U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-258 413

WEIGHTED SENSITIVITY ANALYSIS OF EMISSIONS DATA:

VOLUME I. BACKGROUND AND THEORY

IBM CORPORATION, GAITHERSBURG, MARYLAND

JULY 1973

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-74-022-a	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Weighted Sensitivity Analysis of Emissions Data Volume I - Background and Theory		5. REPORT DATE July 1973 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) F. H. Ditto, L. T. Gutierrez, T. H. Lewis L. J. Rushbrook		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS IBM Corporation 18100 Frederick Pike Gaithersburg, Maryland 20760		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-01-0398
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Protection Agency Research Triangle Park, North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED Final Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report presents a body of analytical techniques appropriate for determining accuracy requirements of component parts of an emissions inventory so as to insure (at a given confidence level) an overall acceptable accuracy in the total inventory. Selected numerical analyses are presented to illustrate application of the techniques to Nationwide Emissions Report data at different levels of aggregation. The results are believed to constitute a significant step in the development of techniques for making reliable forecasts of air pollutant emissions, and have already been applied for such purposes to emissions in Region 5 of the State of Virginia. A report on that application is also included in the present document.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Weighted Sensitivity Analysis Emissions NEDS Data Systems Industrial Classifications Pollutants		

PRICES SUBJECT TO CHANGE

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 133
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE 6.00 - 3.00

I.

EPA Form 2220-1 (9-73)

272057

EPA-450/3-74-022-a
July 1973

PB 258 413

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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

REPRODUCED BY
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U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA-450/3-74-022-a

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VOLUME I -

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by

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Prepared for

ENVRIONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, N. C. 27711

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Publication No. EPA-450/3-74-022-a

WEIGHTED SENSITIVITY ANALYSIS OF EMISSIONS DATA

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PREFACE

The project described in this report was performed under the auspices of the Environmental Protection Agency in conformance with Task Order No. 1, BOA68-01-0398.

The work performed as the Weighted Sensitivity Analysis of Emissions Data project proceeded with unusual effectiveness because of the excellent support provided by the Technical Project Monitor, Mr. John Bosch, and his associates. During the course of the project, Mr. Bosch gave much valuable assistance and guidance which led to the timely and successful completion of the project. Because of these efforts, it was possible to develop additional programs beyond those originally contemplated. The support of Mr. Gerald Nehls to provide basic and test data from the NEDS data was greatly appreciated and directly contributed to the capability to extend the study to include the SCC summarization program.

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WEIGHTED SENSITIVITY ANALYSIS (WSA) OF EMISSION INVENTORIES

The IBM contractual report on weighted sensitivity analysis (WSA) allows users to quantitatively analyze the effects of potential inaccuracies in their air pollution source/emissions inventories. This enables the user to quantify the amount and direction of future resources he must allocate to maintain a given accuracy for his entire emissions inventory. The WSA is one of a series of management tools provided by EPA to effectively interpret emission and source inventories of air pollutant emitters.

WSA is based on the format used and data contained in the National Emissions Data System (NEDS), the official air pollution data base used by EPA. Because a number of States are patterning their emission inventories according to NEDS, the WSA with subsequent modifications is also expected to be useful to non-EPA users, especially to the pollution control agencies using the Comprehensive Data Handling System (CHDS).

The primary objective of WSA is to calculate the maximum allowable variation in emissions for each of the component sub-categories of the emission inventory. This is accomplished by the user first specifying an acceptable error in the total emissions of any criteria pollutant for the geographical area of interest (County, AQCR, State, U. S.). (This is referred to as Θ in the WSA report.)

WSA then applies standard statistical techniques to the NEDS inventory for that geographical area and delivers an "allowable" error for over 100 sub-categories comprising all components of the emission inventory.

WSA calculates the maximum variance in emissions for each sub-category in order to maintain the previously=-specified error for the total inventory. It must be emphasized that WSA does not estimate the actual or existing emission errors for each sub-category: this can only be accomplished by accessing the rew data files of NEDS and estimating the errors due to emission calculations on an individual point and area source basis. An EPA contract is currently underway to perform this function (Source Inventory and Emission Factor Analysis; SIEFA) which will be complementary with WSA and will provide users with an integrated system for error analysis.

Four major assumptions were required for the successful development of WSA:

1. The "on-paper" inventory represents the "real-world" emissions. The necessity of this assumption is apparent: analysis of any data base presupposes that that data base is correct. Any analytical tool becomes more useful to users as the data which it utilizes become more complete.

2. The allowable errors calculated for each sub-category are assumed to be independent of each other. This assumption was necessary to develop the WSA analysis and is justified because any error interdependencies between sub-categories (e.g. population biases) are

considered to be minor compared to the numerous other causes of emission errors for a given sub-category. It should be noted that the sub-category errors are considered to be independent and not the sub-category emissions.

3. Sub-category errors are considered to be random in nature. It is felt that this assumption is, in general, a valid one and WSA was designed with this definition. As described in the WSA report, however, there is a capability to "fix" sub-category errors when known by the user. In this manner, biased or random errors for an individual sub-category can be inserted into WSA whenever they are available. (In such cases, WSA recalculates allowable errors for the remaining sub-categories.)

4. WSA assumes that the distribution of component errors is unknown. This provides for a conservative estimate of the confidence limits to be attached to the θ's (defined in the WSA report as overall errors). There are no known means of estimating the distribution of emission inventory errors although SIEFA will eventually provide such a mechanism; thus the assumption of a normal error distribution seems inappropriate at this time.

It must be emphasized that in analyzing a small subset of inventory data the user should reevaluate the validity of the above WSA assumptions for his project before relying on the technique.

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Section I

INTRODUCTION

This final report documents the work performed under contract BOA 68-01-0398, "Weighted Sensitivity Analysis of Emissions Data". It presents a body of analytical techniques appropriate for determining accuracy requirements of component parts of an emissions inventory so as to insure (at a given confidence level) an overall acceptable accuracy in the total inventory. Selected numerical analyses are presented to illustrate application of the techniques to Nationwide Emissions Report (NER) data at different levels of aggregation. Contract work included development of the necessary software to implement the results of the analysis. The results are believed to constitute a significant step in the development of techniques for making reliable forecasts of air pollutant emissions, and have already been applied for such purposes to emissions in region 5 of the State of Virginia. A report on that application is also included in the present document.

PROJECT BACKGROUND

In 1969, NAPCA established a project called "Projected Growth Data for the Air Quality Control Regions"; in support of this project the U.S. Department of Commerce, Office of Business Economics (OBE), prepared the document, "Economic Projections for Air Quality Control Regions," (PB195805) in June 1970, in ample time to support the nationwide preparation of state air quality control implementation plans.

The preparation of these projections entailed the application of sophisticated techniques by expert econometricians and the utilization of esoteric methodologies by specialists in the Regional Economics Division of OBE.

Although these projections were the best possible, there was no way of predetermining their accuracy or relating economic projection errors to predicted air pollutant emission errors. On the basis of the OBE report's nationwide projections to 1970, the error in projected gross national product was just under 6%, the error in the projected population was 0.75%. The significance of these errors with respect to projected emissions is unkown.

The National Source Inventory Section of EPA processes and publishes data on point and area source emissions of air pollutants, and is responsible for determining the quality of the data used. The emissions inventory is a basic requirement of states' implementation plans and provides EPA with a valuable management tool in the decision-making process associated with the administration of air pollution control activity. It is no longer satisfactory to merely provide an inventory; it is necessary to quantitatively state in statistical terms error existent in a specified inventory. This being the case, the National Source Inventory Section actively sought development of statistical methodology to establish the quality of emissions data.

The methods of weighted sensitivity analysis were chosen as the most flexible approach to develop the necessary techniques, and the Federal Systems Center of IBM Corporation was engaged to perform the necessary theoretical and numerical analyses, as well as to develop the necessary software and its documentation.

PROJECT OBJECTIVES

It is appropriate to summarize at the outset the objectives sought in undertaking the project, as mutually agreed upon between EPA and IBM. The goals to be achieved in the project, as stated in the work scope, were as follows:

1. Analysis

   In this activity, a methodology is to be formally derived whereby accuracy requirements of component parts of an emission inventory can be calculated so as to insure an overall acceptable accuracy in the total inventory. The techniques of weighted sensitivity analysis are to be applied in the performance of this task.

2. Program Development

   In this activity, a FORTRAN computer program for weighted sensitivity analysis is to be designed, coded, tested and debugged. The resulting software will provide a means to evaluate the maximum permissible errors in emissions data with sufficient flexibility to be applicable to both source categories and geographical areas, for a given maximum permissible error of the nationwide inventory. Complete compatibility with NEDS will be assured.

3. Numerical Validation

   In order to demonstrate the adequacy of the analysis and the usage of the computer program, three sample analyses shall be performed (using 1970 nationwide emissions data) to indicate the maximum error in source categories and subcategories (nationwide) for three different nationwide inventory maximum errors to be provided by EPA.

SUMMARY OF RESULTS

Project objectives and requirements as set forth above have been fully achieved. Furthermore, significant developments in both analysis and programming beyond the original goals have been accomplished. A summary of the addtional results obtained is as follows:

1. Refinement of the theoretical weighted sensitivity analysis to distribute both percentage and physical errors in emissions according to their respective weightings.
2. Extension of the analysis to cover the case where one or more of the error components in a given level are to be fixed by the analyst.
3. Modification and/or extension of the software to implement developments 1 and 2 as part of the deliverable program.
4. Parameterization of the software to allow the analyst to apply the program to alternative hierarchial configurations of the emissions data.
5. Extension of the software to permit application of the weighted sensitivity analysis to emissions data at the SCC level of aggregation.
6. Preparation of a comprehensive set of numerical analyses to demonstrate applicability of the technique and adequacy of the computer program. Numerical analyses were conducted for different areas (e.g., county, state, AQCR, U.S.), for different emissions data configurations (e.g., point and area fuel combustion emissions restructured by fuel usage).
7. Consolidated application of weighted sensitivity analysis techniques and Chebyshev's inequality to establish confidence levels for emission inventories.

Section II

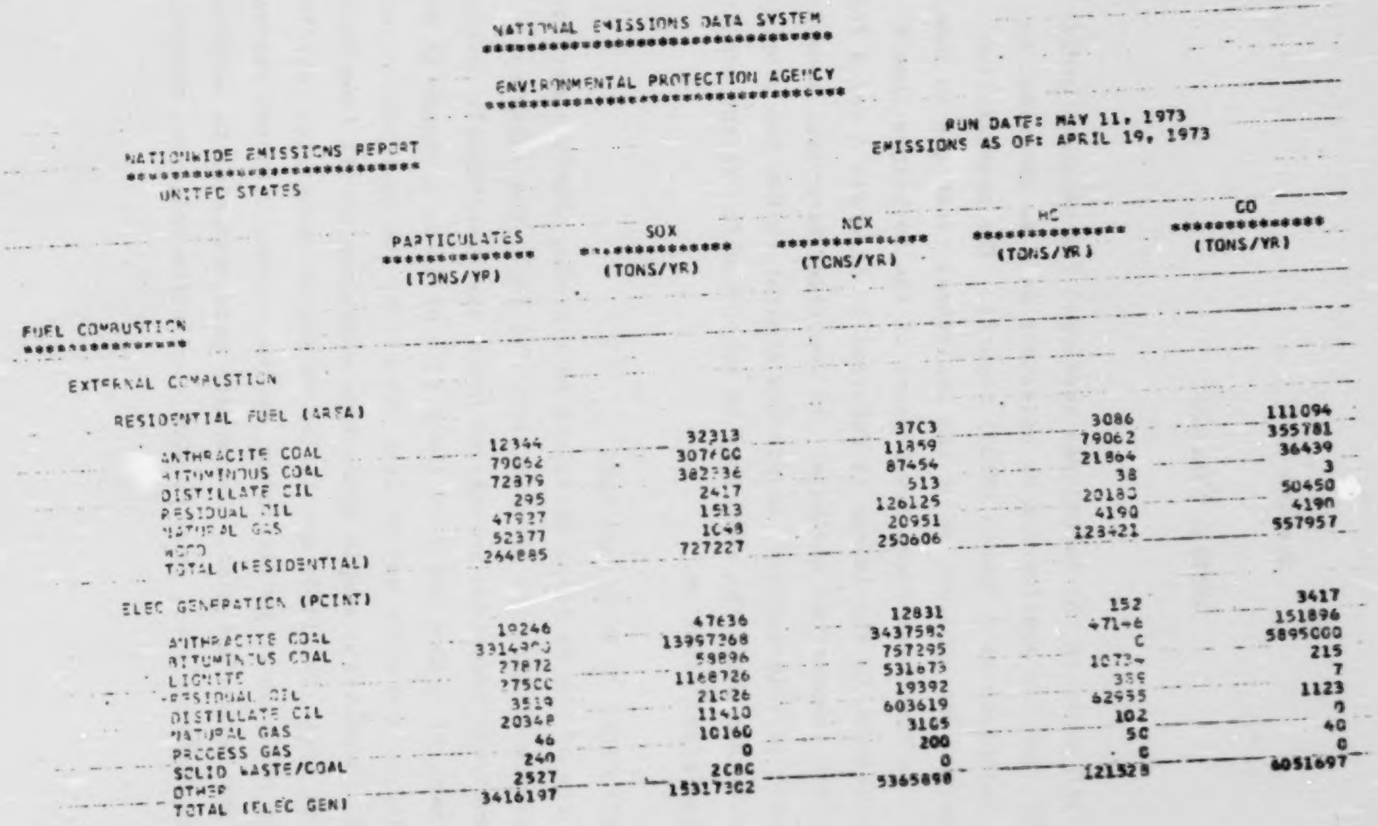
GENERAL ANALYSIS

The section presents the techniques developed for weighted sensitivity analysis and its application to emissions data as contained in the National Emissions Data System (NEDS) reports. The presentation will be focused on the application of the analytical technique to emissions data, rather than the theoretical development of the technique itself. The reader interested in the latter is referred to Appendix A for a full discussion of the theoretical analysis. An annotated numerical example is also included in this section, to provide insight on how the propagation of random error throughout the inventory is accounted for in the application of the weighted error formulae.

HIERARCHIAL STRUCTURE OF EMISSIONS DATA

The reports of the National Emissions Data System (NEDS) constitute the primary source of data for this project. In fact, the weighted sensitivity analysis technique introduced below was specifically developed for the treatment of random error in these sets of data, although it can also be applied to any other set of data processing the same properties.

Figure 2.1 displays a sample nationwide emissions report from NEDS. Emissions as of April 19, 1973, are listed by source categories for five classes of air pollutants: particulates, sulfur oxides, nitrogen oxides, hydrocarbons and carbon monoxide. The source categorization is uniform for other area reports, i.e., county, AQCR, and state emissions reports.



```
                                   NATIONAL EMISSIONS DATA SYSTEM
                                   ******************************

                                   ENVIRONMENTAL PROTECTION AGENCY
                                   *******************************
                                                                              RUN DATE: MAY 11, 1973
        NATIONWIDE EMISSIONS REPORT                                     EMISSIONS AS OF: APRIL 19, 1973
        ***************************
           UNITED STATES

                                                      SOX             NOX              HC              CO
                            PARTICULATES        **************  **************  **************  **************
                           **************         (TONS/YR)       (TONS/YR)       (TONS/YR)       (TONS/YR)
                             (TONS/YR)

FUEL COMBUSTION
***************

  EXTERNAL COMBUSTION

     RESIDENTIAL FUEL (AREA)

        ANTHRACITE COAL          12344           32313            3703            3086          111094
        BITUMINOUS COAL          79062          307600           11859           79062          355781
        DISTILLATE OIL           72879          382336           87454           21864           36439
        RESIDUAL OIL               295            2417             513              38               3
        NATURAL GAS              47927            1513          126125           20183           50450
        WOOD                     52377            1048           20951            4190            4190
        TOTAL (RESIDENTIAL)     264885          727227          250606          123421          557957

     ELEC GENERATION (POINT)

        ANTHRACITE COAL          19246           47636           12831             152            3417
        BITUMINOUS COAL        3314900        13967268         3437582           47146          151896
        LIGNITE                  27872           59896          757295               0         5895000
        RESIDUAL OIL             27500         1168726          531673           10764             215
        DISTILLATE OIL            3519           21026           19392             359               7
        NATURAL GAS              20348           11410          603619           62955            1123
        PROCESS GAS                 46           10160            3165             102               0
        SOLID WASTE/COAL           240               0             200              50              40
        OTHER                     2527            2080               0               0               0
        TOTAL (ELEC GEN)       3416197        15317302         5365898          121528         6051697
```

Figure 2.1 NEDS Data in Tabular Format

INDUSTRIAL FUEL					
ANTHRACITE COAL					
POINT SOURCES	10088	23698	6151	96	1745
BITUMINOUS COAL					
AREA SOURCES	1350782	903767	175953	11730	23460
POINT SOURCES	1233810	2644058	582521	17166	53929
RESIDUAL OIL					
AREA SOURCES	13156	48799	52623	2631	175
POINT SOURCES	54042	759386	166784	3934	605
DISTILLATE OIL					
AREA SOURCES	24531	247475	63994	3202	213
POINT SOURCES	23899	34578	103645	9842	329
NATURAL GAS					
AREA SOURCES	22282	743	222816	49515	495
POINT SOURCES	75866	30178	1483016	170225	4634
PROCESS GAS					
AREA SOURCES	5	0	71	12	0
POINT SOURCES	10885	94790	8255	56	2
COKE					
POINT SOURCES	1143	1706	0	0	0
WOOD					
AREA SOURCES	1460	29	584	117	117
POINT SOURCES	147086	9695	97072	21104	19487
LIQUID PETROL GAS					
POINT SOURCES	256	24	1703	561	1
OTHER					
POINT SOURCES	5066	3341	237	29	7723
TOTAL (INDUSTRIAL)					
AREA SOURCES	1412216	1200813	516042	67205	24461
POINT SOURCES	1562142	3601454	2449426	223016	88455
COMM-INSTITUTIONAL FUEL					
ANTHRACITE COAL					
AREA SOURCES	504	551	221	4	133
POINT SOURCES	236	1351	86	2	114
BITUMINOUS COAL					
AREA SOURCES	144322	221777	26351	5728	20623
POINT SOURCES	59973	86897	17330	1657	4882
RESIDUAL OIL					
AREA SOURCES	51432	596161	134300	6715	448
POINT SOURCES	7730	80474	20031	954	84
DISTILLATE OIL					
AREA SOURCES	60861	217820	243443	12172	811
POINT SOURCES	743	4355	2611	132	10
NATURAL GAS					
AREA SOURCES	17787	560	93352	7468	18670
POINT SOURCES	20888	2945	124134	8575	20585
WOOD					
AREA SOURCES	102	2	41	8	8
POINT SOURCES	586	49	625	140	125
LIQUID PETROL GAS					
POINT SOURCES	2	0	10	1	2
TOTAL (COMM-INST)					
AREA SOURCES	275009	1036922	497708	32096	40693
POINT SOURCES	90158	176071	164827	11461	25803
OTHERS (POINT)	2741	211	246	0	0
TOTAL (EXTERNAL COMB)					
AREA SOURCES	1952109	2964962	1264356	227722	623111
POINT SOURCES	5070238	19095039	7980397	356005	6165954

Figure 2.1 (cont.)

INTERNAL COMBUSTION (POINT)					
ELECTRIC GENERATION					
DISTILLATE OIL	1043	2371	8287	62	92
NATURAL GAS	13	0	3523	0	0
DIESEL	94	196	2687	269	1634
TOTAL (ELEC GEN)	1151	2567	14498	331	1726
INDUSTRIAL FUEL					
DISTILLATE OIL	86	408	920	35	212
NATURAL GAS	1285	7295	828953	27637	10423
GASOLINE	9	4	168	491	1228
DIESEL FUEL	48	87	1245	128	729
TOTAL (INDUSTRIAL)	1429	7799	831285	28291	12592
COMM-INSTITUTIONAL					
DIESEL	47	97	1328	133	808
OTHER	6	2	11	9	3
TOTAL (COMM-INST)	53	99	1339	142	811
ENGINE-TESTING					
AIRCRAFT	172	72	397	377	940
OTHER	151	0	0	0	0
TOTAL (ENG TESTNG)	323	72	397	377	940
OTHER (POINT)	0	0	0	220	0
TOTAL (INTERNAL COMB)	2956	10537	947519	29360	16069
TOTAL (FUEL COMBUSTION)					
AREA SOURCES	1952109	2964961	1264356	227722	623111
POINT SOURCES	5073194	19105576	8827916	385365	6182023
INDUSTRIAL PROCESS (POINT)					
**************************					
CHEMICAL MANUFACTURING	194243	431773	91649	2151455	5799504
FOOD/AGRICULTURAL	215492	912	2989	22255	548
PRIMARY METAL	1476560	3792555	15060	111779	2980138
SECONDARY METALS	144426	89536	1776	2264	1393596
MINERAL PRODUCTS	4589503	305369	99161	7559	18723
PETROLEUM INDUSTRY	1432023	1832762	3020727	865146	7254689
WOOD PRODUCTS	323630	81283	2230	12764	527647
EVAPORATION	881	2545	545	1598193	2110
METAL FABRICATION	4035	2266	905	1002	38
LEATHER PRODUCTS	0	0	0	380	0
TEXTILE MANUFACTURING	501	40	0	4778	0
INPROCESS FUEL	20592	30513	16618	12479	4881
OTHER/NOT CLASSIFIED	8364	10908	433	93637	30860
TOTAL (INDUSTRIAL)	8410250	6580464	3252095	4883692	18012733

Figure 2.1 (cont.)

```
SOLID WASTE DISPOSAL
********************

  GOVERNMENT (POINT)

     MUNICIPAL INCINERATION        34619        5323        4268       12453       64403
     OPEN BURNING                  26039        1597        9503       49278      137467
     TOTAL (GOVERNMENT)            60658        6920       13771       60731      201869

  RESIDENTIAL (AREA)

     ON SITE INCINERATION         179419        2990        5981      598064     1794192
     OPEN BURNING                 114906        7182       43090      244174      610436
     TOTAL (RESIDENTIAL)          294325       10172       49070      842236     2404628

  COMMERCIAL-INSTITUTIONAL

     ON SITE INCINERATION
         AREA SOURCES              31949        3994        5325       26624       53248
         POINT SOURCES              1263         761         534        1341       10989
     OPEN BURNING
         AREA SOURCES              38554        2410       14458       81928      204820
         POINT SOURCES              1159           0         136         273        3409
     APARTMENT
         POINT SOURCES              1104          19         116         552         740
     TOTAL (COMM-INST)
         AREA SOURCES              70503        6403       19783      108552      258068
         POINT SOURCES              3527         779         786        2166       15138

  INDUSTRIAL

     ON SITE INCINERATION
         AREA SOURCES             147877       18485       24646      123230      246461
         POINT SOURCES             62791       17945        7786       55589      587646
     OPEN BURNING
         AREA SOURCES             104570        6536       39214      222212      555530
         POINT SOURCES             14246         255        2766       34923       48957
     AUTO BODY INCINERATION
         POINT SOURCES                14           0           1           3          17
     OTHER
         POINT SOURCES                38        3150           8          79          22
     TOTAL (INDUSTRIAL)
         AREA SOURCES             252447       25020       63860      345443      801991
         POINT SOURCES             77089       21350       10562       90594      636643

  OTHER (POINT)                        7           0           0           0           0

  TOTAL (SOLID WASTE DISP)

     AREA SOURCES                 617275       41595      132713     1296233     3464687
     POINT SOURCES                141280       29049       25119      153482      853650
```

Figure 2.1 (cont.)

```
TRANSPORTATION (AREA)
*********************

  LAND VEHICLES

    GASOLINE

      LIGHT VEHICLES              344770       206862      4991699     10522889     57097621
      HEAVY VEHICLES               20573        12344       635779      1397178      5754393
      OFF HIGHWAY                  11900         7437       261797       822577      4507067
      TOTAL (GASOLINE)            377243       226643      5889274     12742645     67359081

    DIESEL

      HEAVY VEHICLES               40210        80421      1139292       113929       670172
      OFF HIGHWAY                  15494        32180       440984        44098       268166
      RAIL                         52197       135712       156591       104394       146151
      TOTAL (DIESEL)              107901       248312      1736867       262421      1084489

  AIRCRAFT

    MILITARY                      147475        28161        70847       343120       368317
    CIVIL                           8438         1676         7622        37369       213538
    COMMERCIAL                     55226        12235        34551       132542       314362
    TOTAL (AIRCRAFT)              211138        42071       113021       513031       896217

  VESSELS

    BITUMINOUS COAL                 1273         3183          191         1273         5729
    DIESEL FUEL                    13667        35535        41002        27334        38268
    RESIDUAL OIL                    6036        26242        15745          790           52
    GASOLINE                         823          514        18095        56856       311523
    TOTAL (VESSELS)                21799        65474        75033        86253       355573

  GAS HANDLING EVAP LOSS               0            0            0       913379            0

  TOTAL (TRANSPORTATION)          718081       582501      7814195     14517727     69695361

MISCELLANEOUS (AREA)
********************

  SLASH BURNING                   220278            0        25915       259150       777451
  SOLVENT EVAPORATION LOSS             0            0            0      1383855            0
  TOTAL (MISCELLANEOUS)           220278            0        25915      1643005       777451

OTHER (POINT)                          0            0            0            0            0
*************

GRAND TOTAL
***********

  AREA SOURCES                   3507743      3589057      9237179     17684687     74560610
  POINT SOURCES                 13624732     25715089     12105130      5422538     25048407
  TOTAL                         17132475     29304146     21342309     23107225     99609017
```

Figure 2.1 (cont.)

From the viewpoint of analysis, the most important property of these sets of data is their hierarchial nature. In fact, the tabular source categorization of the NEDS reports can be best understood if its hierarchial structure is explicitly recognized. This can be effectively done by converting the tabular format of Figure 2.1 to a tree format, as shown in Figure 2-2. Taking the grand total of the very bottom of the table in Figure 2.1 as the starting point or highest level, the tree unfolds back hierarchially through four and sometimes five successively lower levels of aggregation, the lowest level being the elementary emissions data for each segment of the tree.

The tree format of Figure 2.2 provides a convenient, systematic representation of an emissions inventory for analysis purposes. Each node of the tree, together with the branches coming out of it, constitutes a level of error propagation in the inventory. Therefore, the weighted sensitivity analysis must be applied hierarchially, starting with the allowable error for the grand total (i.e., the overall allowable error), so as to compute allowable errors for each one of the branches which, if satisfied, insure that the overall allowable error is not exceeded.

Figure 2.2 displays the tree of source nodes and branches, numerically annotated to facilitate the discussion. Thus, for example, node 1.1 (fuel combustion-point) has two branches denoted as 1.1.1 and 1.1.2 (external combustion and internal combustion, respectively). The emission quantity (in tons/year) associated with each branch throughout the tree is of course read from the appropriate total, subtotal or elementary data item in the NEDS table of Figure 2.1. This is illustrated in Figure 2.3, which displays a segment of the tree with the actual particulate emission quantities for each branch. For example, 3416197 tons/year of particualte emissions is shown as originating from electricity generation through external fuel

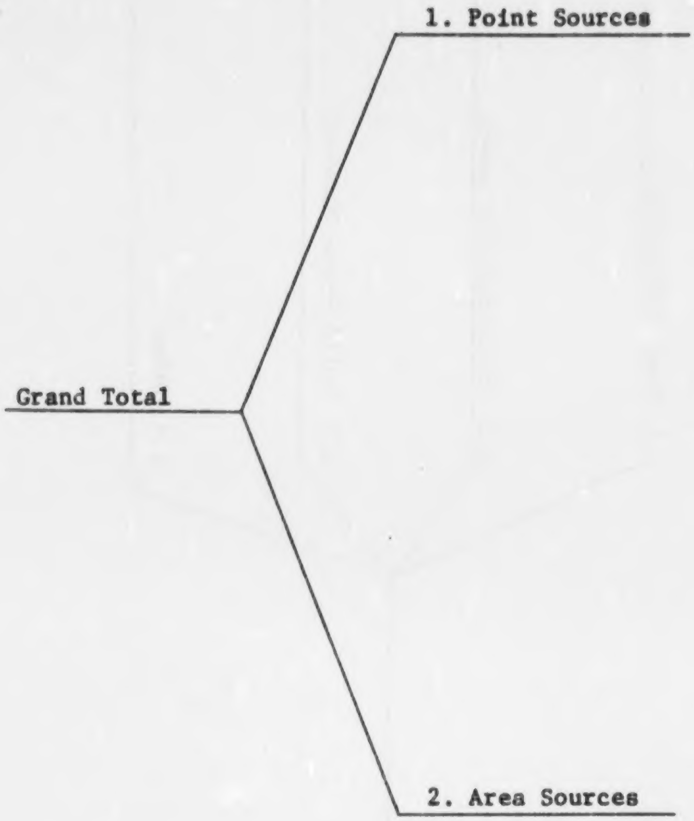

1. Point Sources
Grand Total
2. Area Sources

Figure 2.2 NEDS source categories in tree format

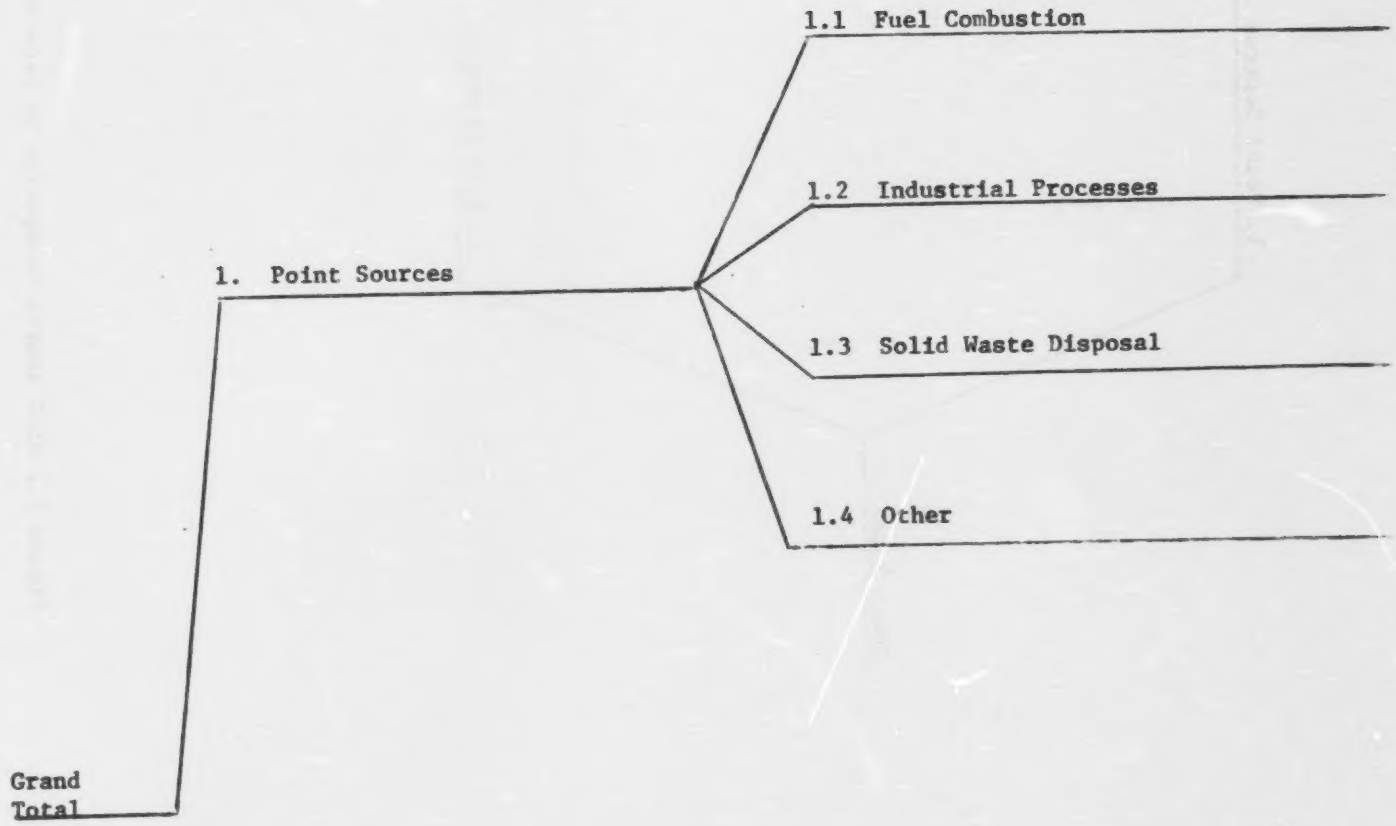

1.1 Fuel Combustion
1.2 Industrial Processes
1.3 Solid Waste Disposal
1.4 Other
1. Point Sources
Grand Total

Figure 2.2 (cont.)

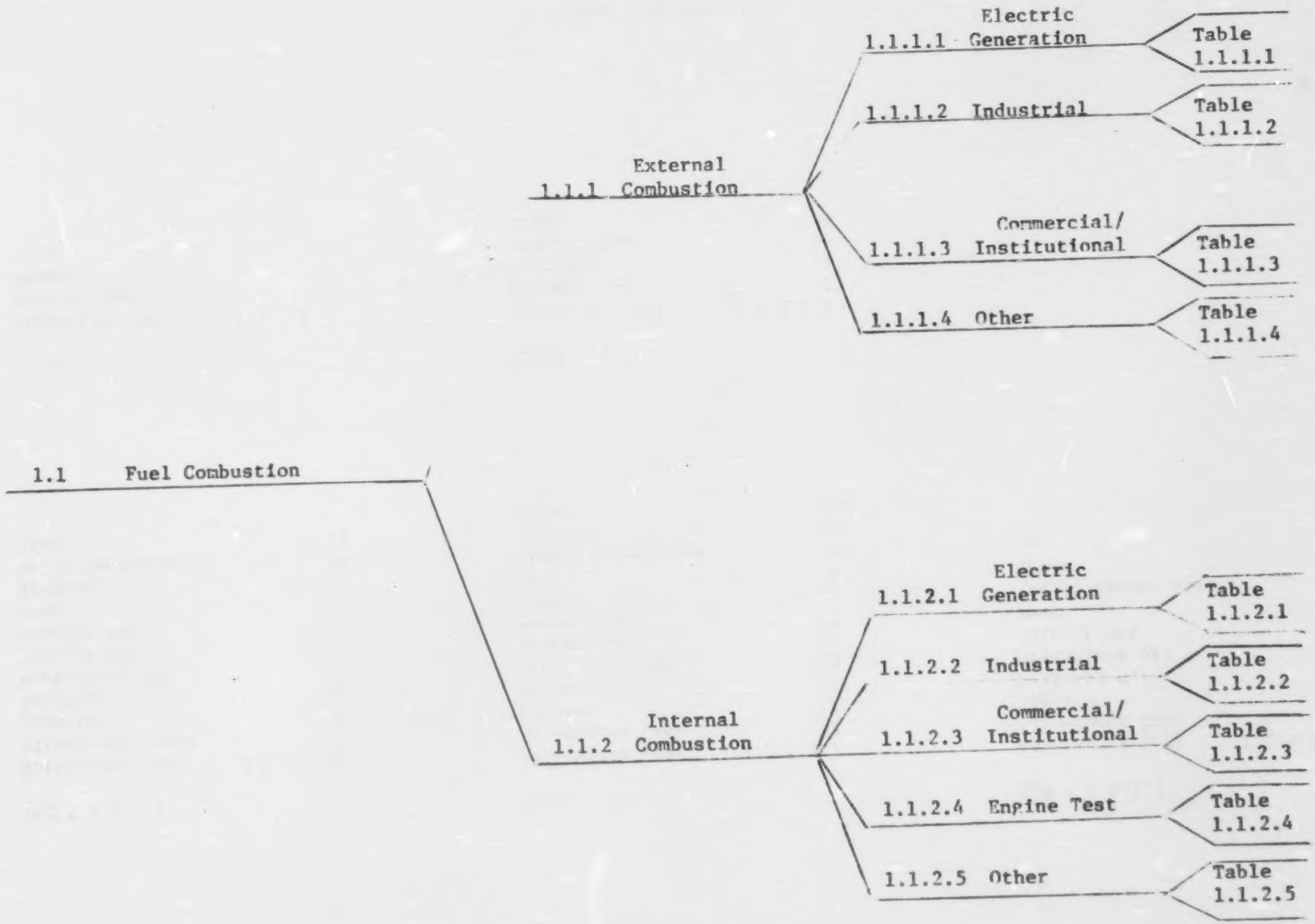

Electric
1.1.1.1 Generation
Table 1.1.1.1
1.1.1.2 Industrial
Table 1.1.1.2
External
1.1.1 Combustion
Commercial/
1.1.1.3 Institutional
Table 1.1.1.3
1.1.1.4 Other
Table 1.1.1.4
1.1 Fuel Combustion
Electric
1.1.2.1 Generation
Table 1.1.2.1
1.1.2.2 Industrial
Table 1.1.2.2
Internal
1.1.2 Combustion
Commercial/
1.1.2.3 Institutional
Table 1.1.2.3
1.1.2.4 Engine Test
Table 1.1.2.4
1.1.2.5 Other
Table 1.1.2.5

Figure 2.2 (cont.)

TABLE 1.1.1.1

Anthracite Coal	1.1.1.1.1
Bituminous Coal	.2
Lignite	.3
Residual Oil	.4
Distillate Oil	.5
Natural Gas	.6
Process Gas	.7
Coke	.8
Bagasse	.9
Solid Waste/Coal	.10
Other	.11

TABLE 1.1.1.2

Anthracite Coal	1.1.1.2.1
Bituminous Coal	.2
Lignite	.3
Residual Oil	.4
Distillate Oil	.5
Natural Gas	.6
Process Gas	.7
Coke	.8
Wood	.9
Liquid Petrol Gas	.10
Bagasse	.11
Other	.12

TABLE 1.1.1.3

Anthracite Coal	1.1.1.3.1
Bituminous Coal	.2
Lignite	.3
Residual Oil	.4
Distillate Oil	.5
Natural Gas	.6
Wood	.7
Liquid Petrol Gas	.8
Other	.9

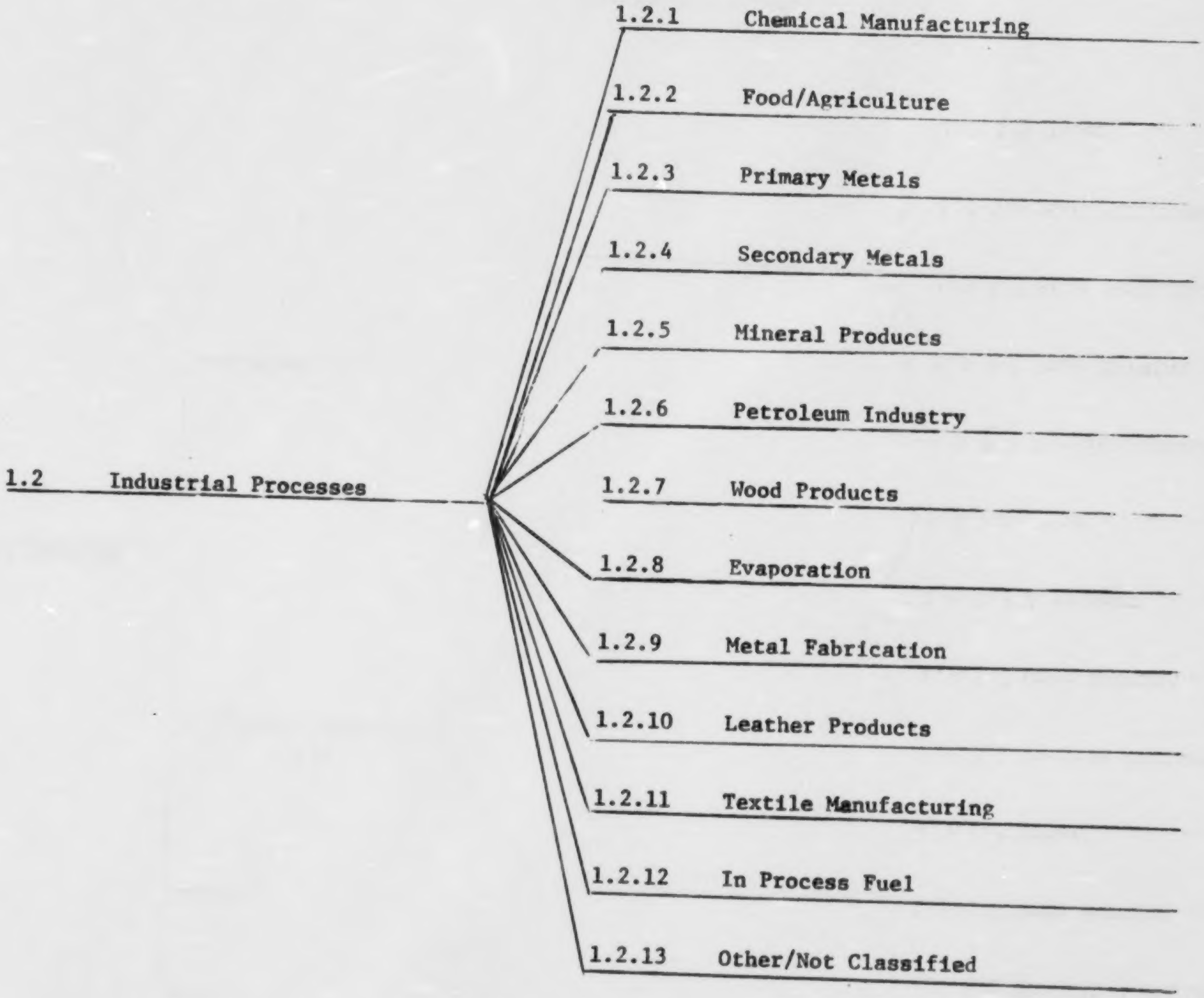
TABLE 1.1.2.1

Distillate Oil	1.1.2.1.1
Natural Gas	.2
Diesel	.3
Other	.4

TABLE 1.1.2.2

Distillate Oil	1.1.2.2.1
Natural Gas	.2
Gasoline	.3
Diesel Fuel	.4
Other	.5

Figure 2.2 (cont.)



1.2 Industrial Processes
1.2.1 Chemical Manufacturing
1.2.2 Food/Agriculture
1.2.3 Primary Metals
1.2.4 Secondary Metals
1.2.5 Mineral Products
1.2.6 Petroleum Industry
1.2.7 Wood Products
1.2.8 Evaporation
1.2.9 Metal Fabrication
1.2.10 Leather Products
1.2.11 Textile Manufacturing
1.2.12 In Process Fuel
1.2.13 Other/Not Classified

Figure 2.2 (cont.)

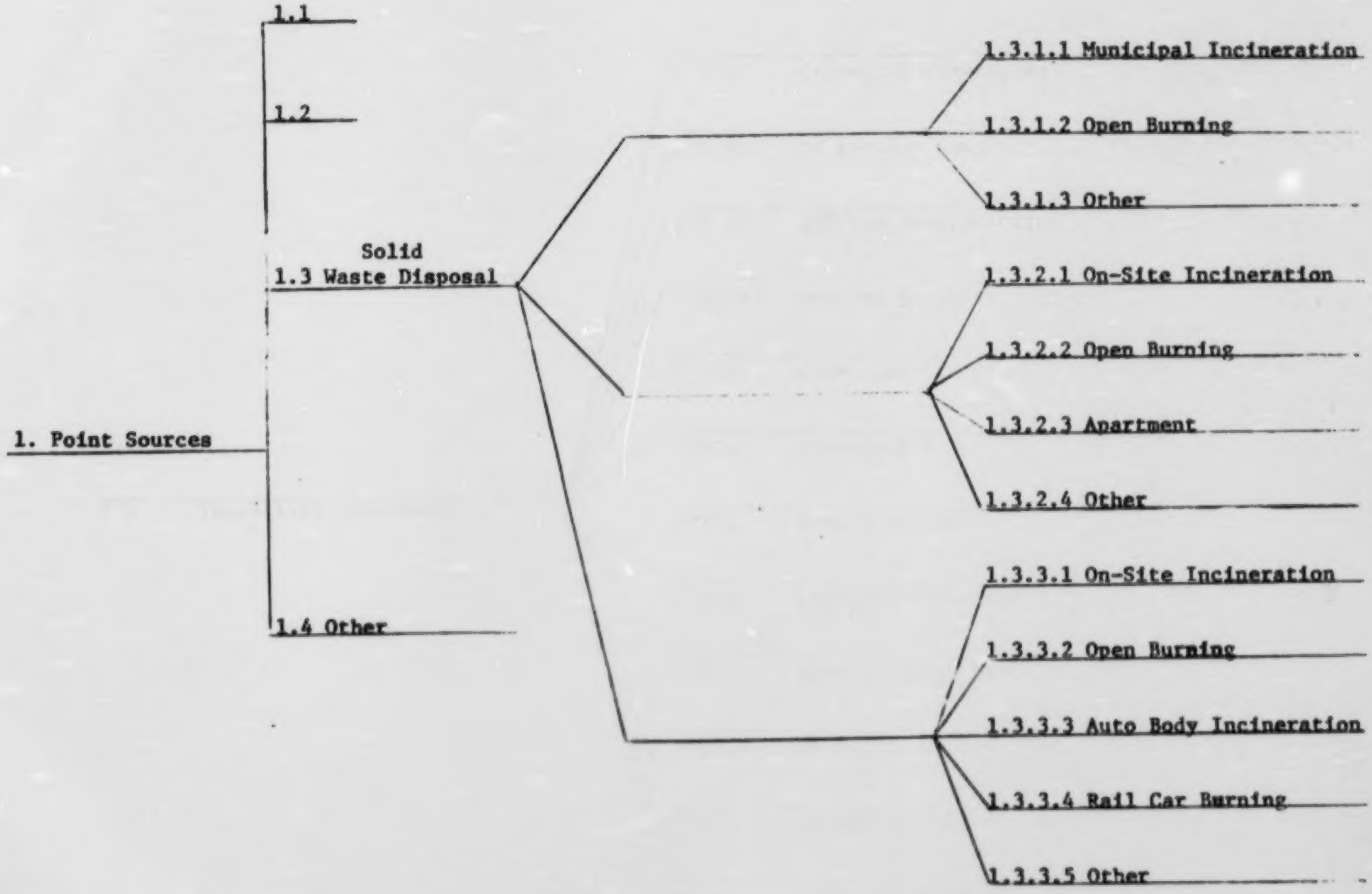

1. Point Sources
1.1
1.2
Solid
1.3 Waste Disposal
1.4 Other
1.3.1.1 Municipal Incineration
1.3.1.2 Open Burning
1.3.1.3 Other
1.3.2.1 On-Site Incineration
1.3.2.2 Open Burning
1.3.2.3 Apartment
1.3.2.4 Other
1.3.3.1 On-Site Incineration
1.3.3.2 Open Burning
1.3.3.3 Auto Body Incineration
1.3.3.4 Rail Car Burning
1.3.3.5 Other

Figure 2.2 (cont.)

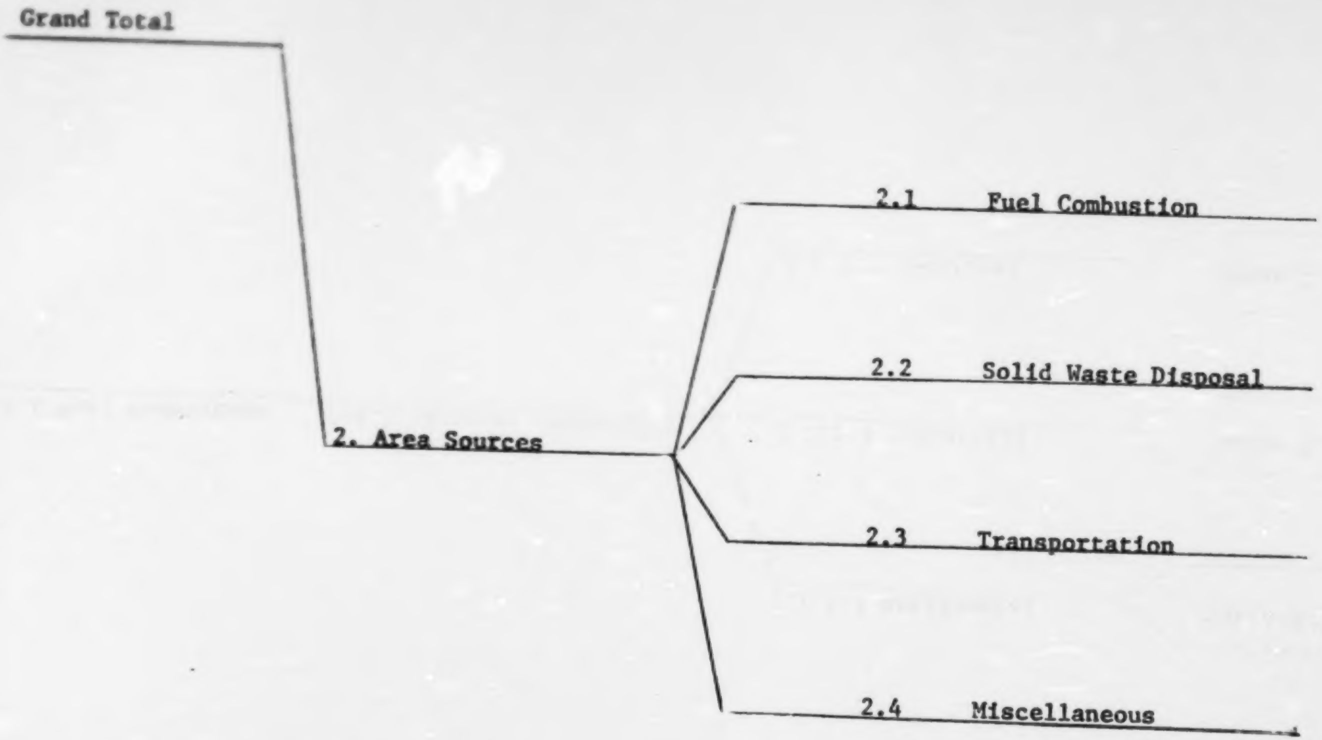

Grand Total
2. Area Sources
2.1 Fuel Combustion
2.2 Solid Waste Disposal
2.3 Transportation
2.4 Miscellaneous

Figure 2.2 (cont.)

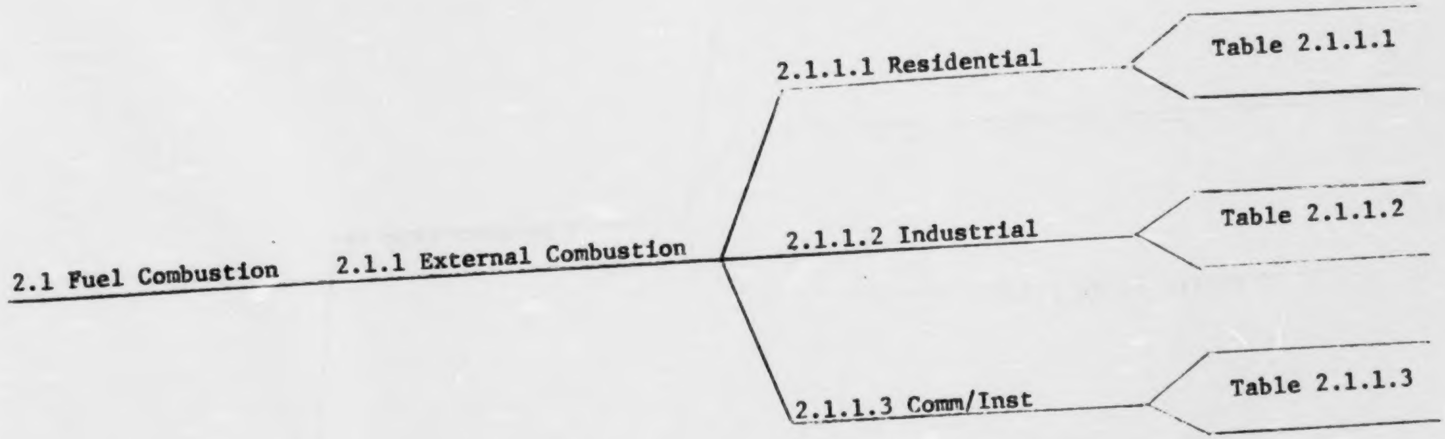

2.1 Fuel Combustion
2.1.1 External Combustion
2.1.1.1 Residential
2.1.1.2 Industrial
2.1.1.3 Comm/Inst
Table 2.1.1.1
Table 2.1.1.2
Table 2.1.1.3

Figure 2.2 (cont.)

TABLE 2.1.1.1

Anthracite Coal	2.1.1.1.1
Bituminous Coal	2.1.1.1.2
Distillate Oil	2.1.1.1.3
Residual Oil	2.1.1.1.4
Natural Gas	2.1.1.1.5
Wood	2.1.1.1.6

TABLE 2.1.1.2

Anthracite Coal	2.1.1.2.1
Bituminous Coal	2.1.1.2.2
Residual Oil	2.1.1.2.3
Distillate Oil	2.1.1.2.4
Natural Gas	2.1.1.2.5
Process Gas	2.1.1.2.6
Coke	2.1.1.2.7
Wood	2.1.1.2.8

TABLE 2.1.1.3

Anthracite Coal	2.1.1.3.1
Bituminous Coal	2.1.1.3.2
Residual Oil	2.1.1.3.3
Distillate Oil	2.1.1.3.4
Natural Gas	2.1.1.3.5
Wood	2.1.1.3.6

Figure 2.2 (cont.)

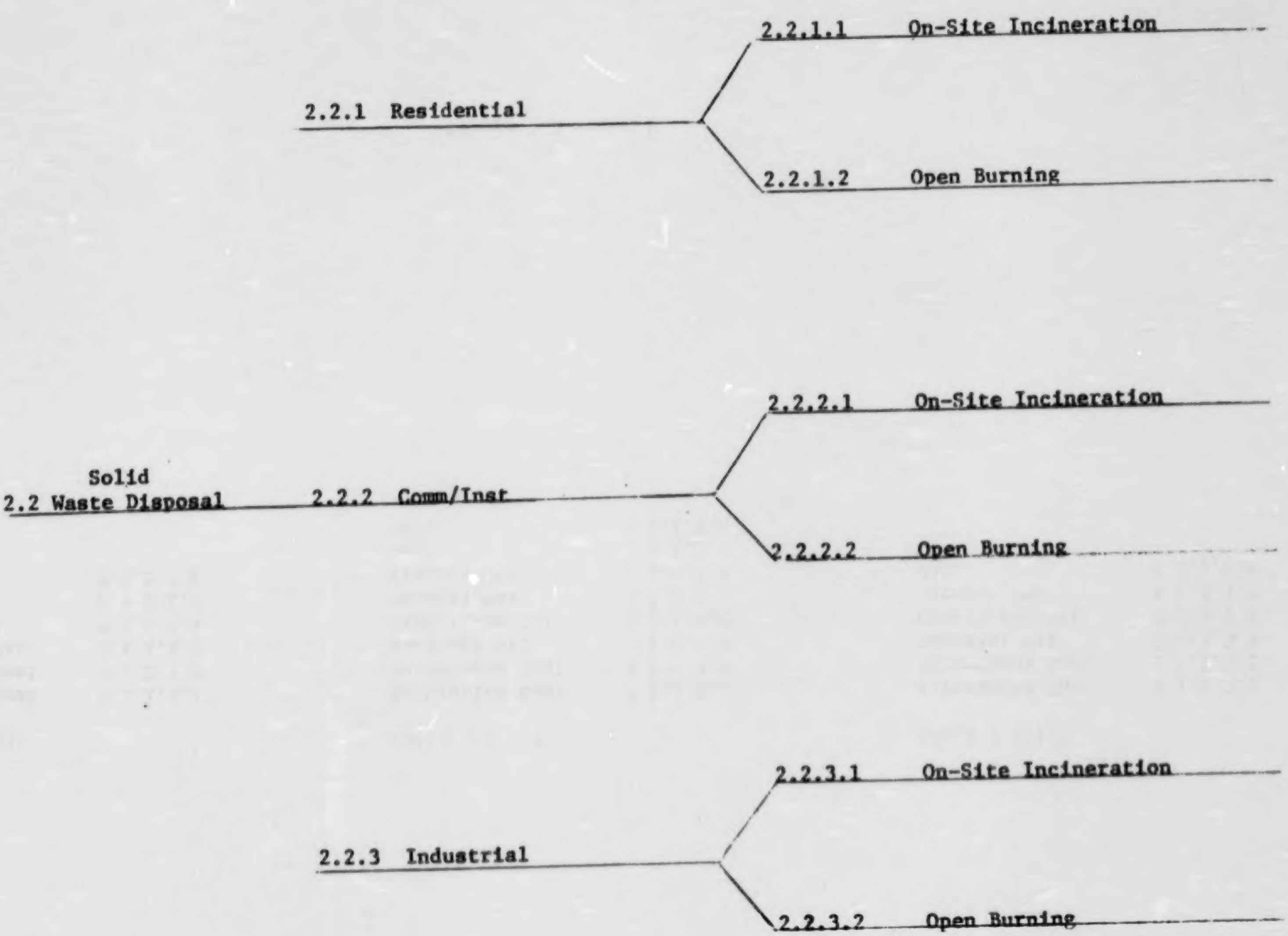

2.2.1.1 On-Site Incineration
2.2.1 Residential
2.2.1.2 Open Burning
2.2.2.1 On-Site Incineration
Solid
2.2 Waste Disposal
2.2.2 Comm/Inst
2.2.2.2 Open Burning
2.2.3.1 On-Site Incineration
2.2.3 Industrial
2.2.3.2 Open Burning

Figure 2.2 (cont.)

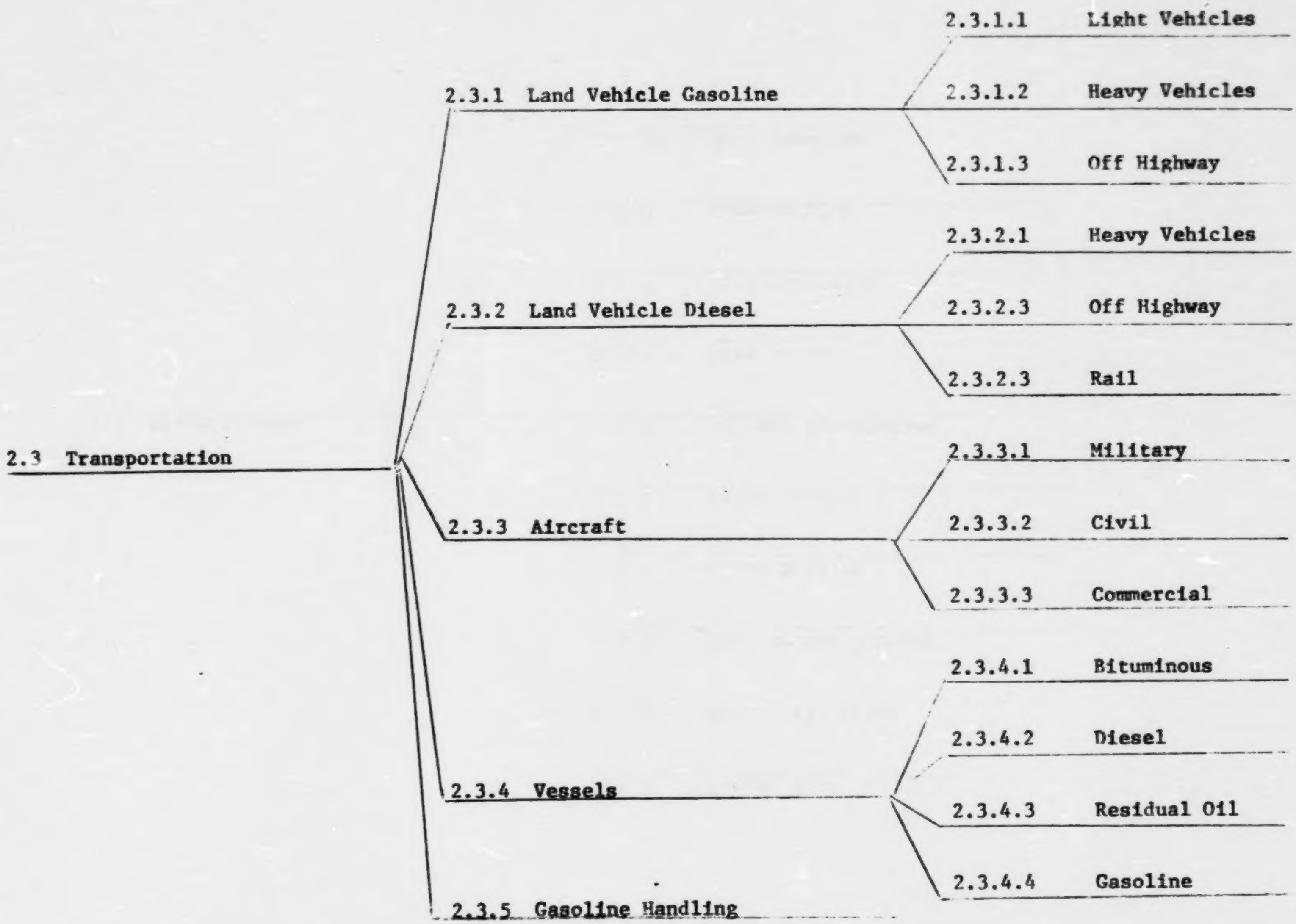

2.3 Transportation
2.3.1 Land Vehicle Gasoline
2.3.1.1 Light Vehicles
2.3.1.2 Heavy Vehicles
2.3.1.3 Off Highway
2.3.2 Land Vehicle Diesel
2.3.2.1 Heavy Vehicles
2.3.2.3 Off Highway
2.3.2.3 Rail
2.3.3 Aircraft
2.3.3.1 Military
2.3.3.2 Civil
2.3.3.3 Commercial
2.3.4 Vessels
2.3.4.1 Bituminous
2.3.4.2 Diesel
2.3.4.3 Residual Oil
2.3.4.4 Gasoline
2.3.5 Gasoline Handling

Figure 2.2 (cont.)

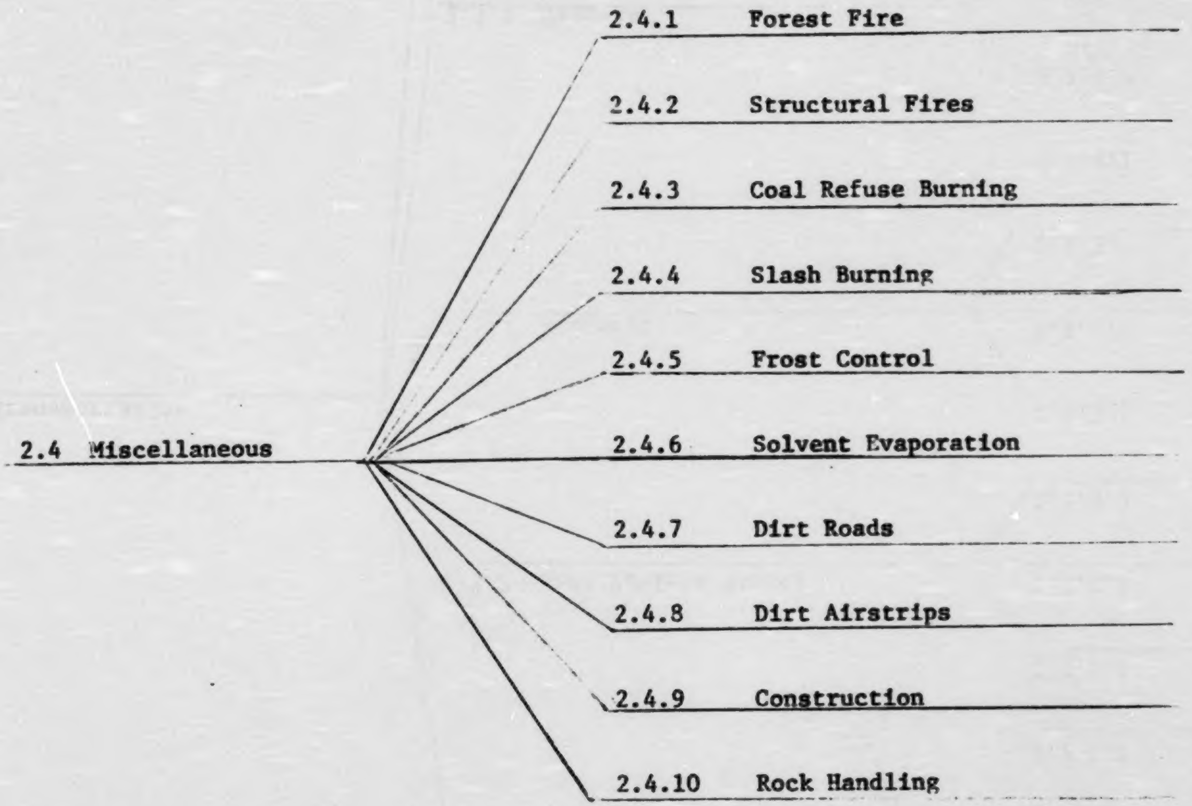

2.4 Miscellaneous
2.4.1 Forest Fire
2.4.2 Structural Fires
2.4.3 Coal Refuse Burning
2.4.4 Slash Burning
2.4.5 Frost Control
2.4.6 Solvent Evaporation
2.4.7 Dirt Roads
2.4.8 Dirt Airstrips
2.4.9 Construction
2.4.10 Rock Handling

Figure 2,2 (cont.)

combustion at point sources. Observe that the summation of the emissions associated with their node. This relationship will be the basis for the weightings to be used below in computing allowable errors for each branch of the tree.

WEIGHTED SENSITIVITY ANALYSIS

In this project, the mathematics of sensitivity analysis were directed to the development of accuracy requirements for the component parts of an emissions inventory such that a given accuracy requirement for the overall inventory is satisfied. The objective of sensitivity analysis is to determine the effect (changes) on some measure of performance due to changes in each component that makes up the measure of performance. In the simplest case the measure of performance is the sum of component measures. In the case of an emissions inventory, it was shown above that the total emissions for a given source class is always equal to the sum of the emissions from the source subclasses in that class. Furthermore, since each one of these emissions have been independently measured, it follows that the overall squared error for the source class is a linear function of the squared errors of the source subclasses.

This analysis is based on statistical linear models and their application to represent propagation of error in sets of data (References 1,2,5). For clarity of presentation, the discussion in this subsection will be focused on the main analytical results, their statistical interpretation, and their practical implications. Detailed mathematical derivations of all formulae are given in Appendix A.

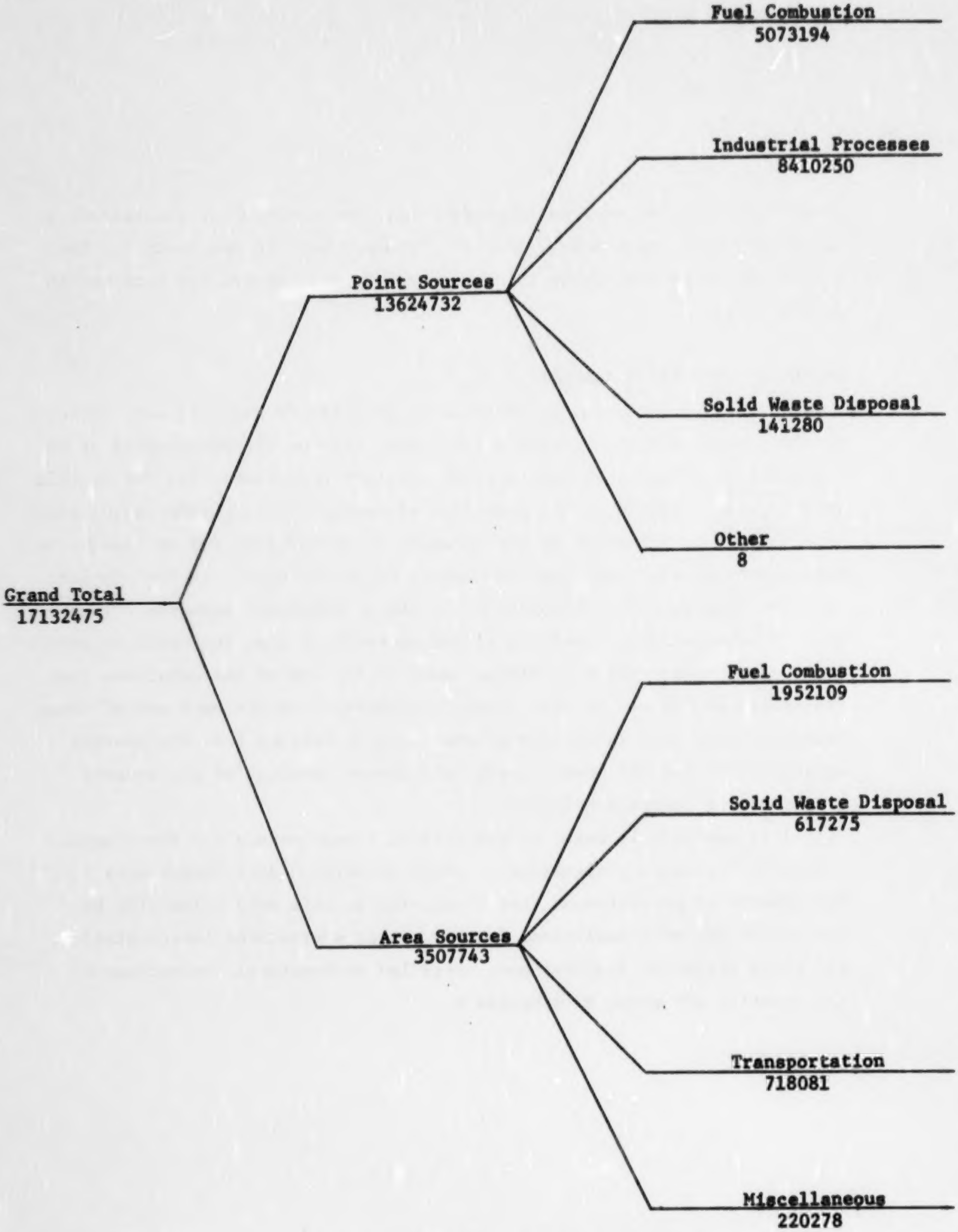

Fuel Combustion
5073194
Industrial Processes
8410250
Point Sources
13624732
Solid Waste Disposal
141280
Other
8
Grand Total
17132475
Fuel Combustion
1952109
Solid Waste Disposal
617275
Area Sources
3507743
Transportation
718081
Miscellaneous
220278

Figure 2.3 NEDS data in tree format

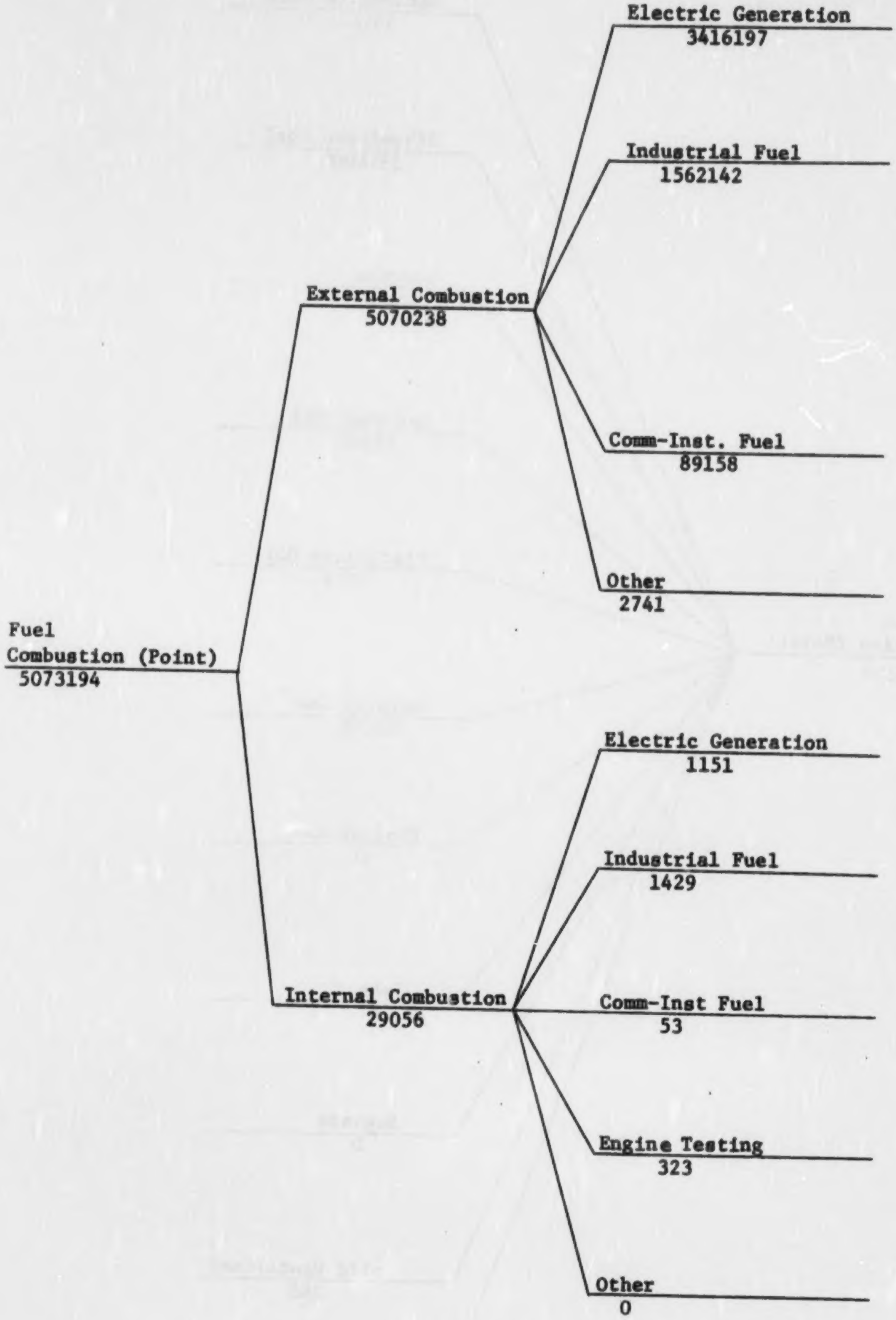

Electric Generation
3416197
Industrial Fuel
1562142
External Combustion
5070238
Comm-Inst. Fuel
89158
Other
2741
Fuel
Combustion (Point)
5073194
Electric Generation
1151
Industrial Fuel
1429
Internal Combustion
29056
Comm-Inst Fuel
53
Engine Testing
323
Other
0

Figure 2.3 (cont.)

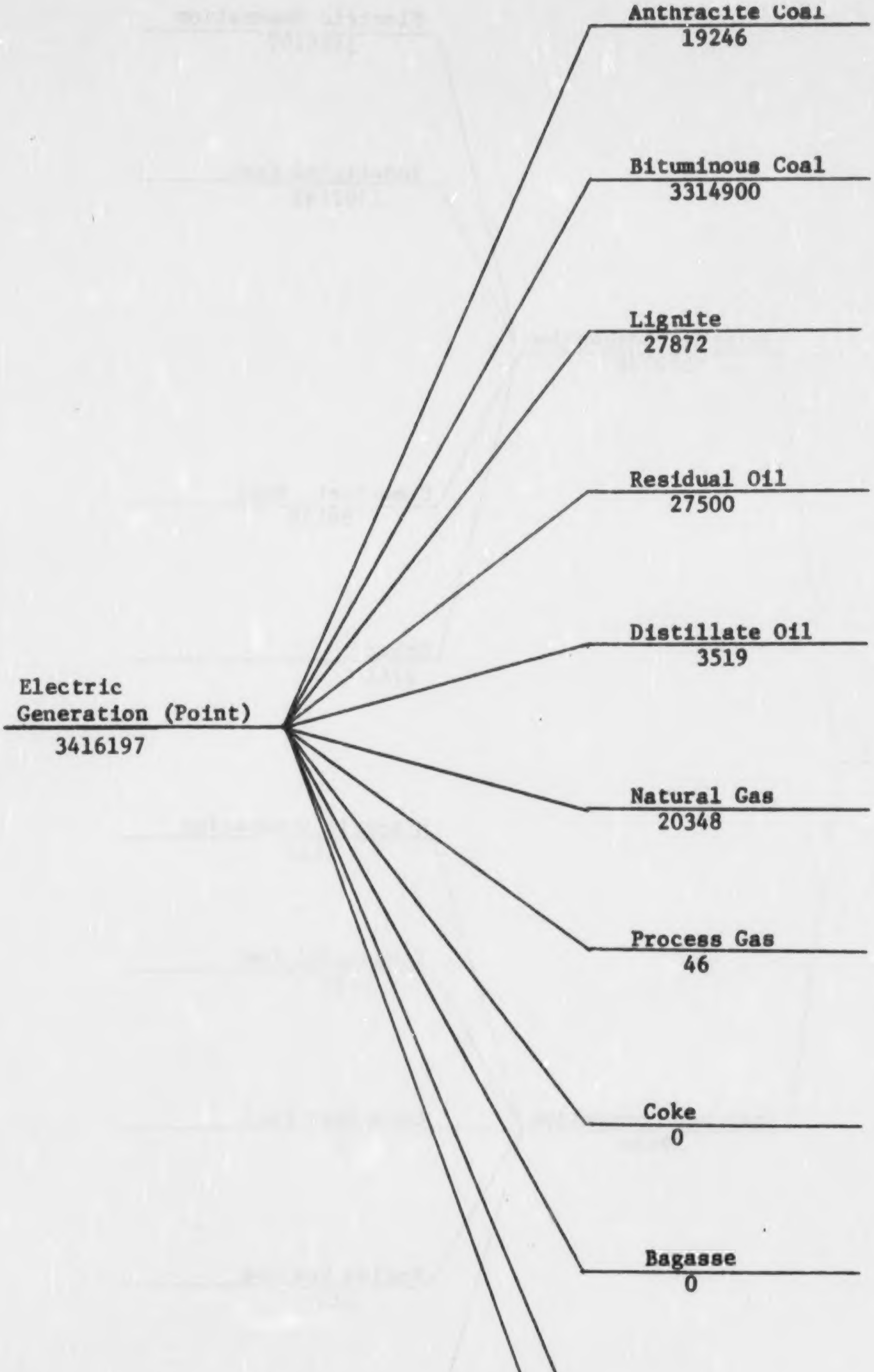

Anthracite Coal
19246
Bituminous Coal
3314900
Lignite
27872
Residual Oil
27500
Distillate Oil
3519
Electric
Generation (Point)
3416197
Natural Gas
20348
Process Gas
46
Coke
0
Bagasse
0
Solid Waste/Coal
240
Other
2527

Figure 2.3 (cont.)

The basic theoretical development proceeds as follows. The linear model

$$Q^2\Theta^2 = \sum_{K=1}^{N} Q_K^2 \sigma_K^2 \qquad (1)$$

where

Q_K = air pollutant produced by source subclass K

100 σ_K = percentage error associated with Q_K

$Q = \sum_{K=1}^{N} Q_K$

100 Θ = percentage error associated with Q

N = number of subclasses in the source class

is postulated as an appropriate model to analyze propogation of error throughout the emissions inventory, for hte reasons stated above. For example, with reference to the external combustion node of Figure 2.3, we would have

Q_1 = 3416197 tons/yr.
Q_2 = 1562142 tons/yr.
Q_3 = 89158 tons/yr.
Q_4 = 2741 tons/yr.
$Q = \sum_{K=1}^{4} Q_K$ = 5070238 tons/yr.

Dividing both sides of equation (1) by $Q^2\Theta^2$

$$1 = \sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \tag{2}$$

The objective of this analysis is to obtain σ_K for each class k according to some value of Θ (error in total). As a first approximation we can assume that each term in Equation (2) contributes the same amount to the total.

$$\frac{1}{N} = \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \tag{3}$$

whence

$$\sigma_K = \frac{\Theta}{\sqrt{N}\,(Q_K/Q)}$$

where N is the number of source classes.

As a second approximation, the analysis can be modified to recognize the fact that each source class k contributes to the total error an amount proportional to its relative physical contribution to the total pollutant emission Q, as given by the ratio Q_K/Q. Analytically, it is only necessary to note that

$$\sum_{K=1}^{N} \frac{Q_K}{Q} = 1$$

Therefore, from equation (2):

$$\sum_{K=1}^{N} \frac{Q_K}{Q} = \sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\theta}\right)^2 \tag{5}$$

Equating both sides of ea. (5) term-by-term is equivalent to assuming that each term contributes to the total an amount proportional to Q_K/Q:

$$\frac{Q_K}{Q} = \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\theta}\right)^2 \tag{6}$$

whence

$$\sigma_K = \theta \sqrt{\frac{Q}{Q_K}} \tag{7}$$

We can interpret Equation (7) as indicating the percent error allowable (σ_K) in forecasting emissions from source class K given the percent error desired (θ) in forecasting total emissions. σ_K can be modified either by changing Θ or by regrouping the source classes, which changes Q/Q_K . The latter method is particularly useful in that it allows modification of σ_K without changing Θ . A useful policy for regrouping the source classes is to assemble the classes with the smallest emissions into one or more classes; however, this policy should be applied with some discretion in order to have groups or classes that can be successfully forecast.

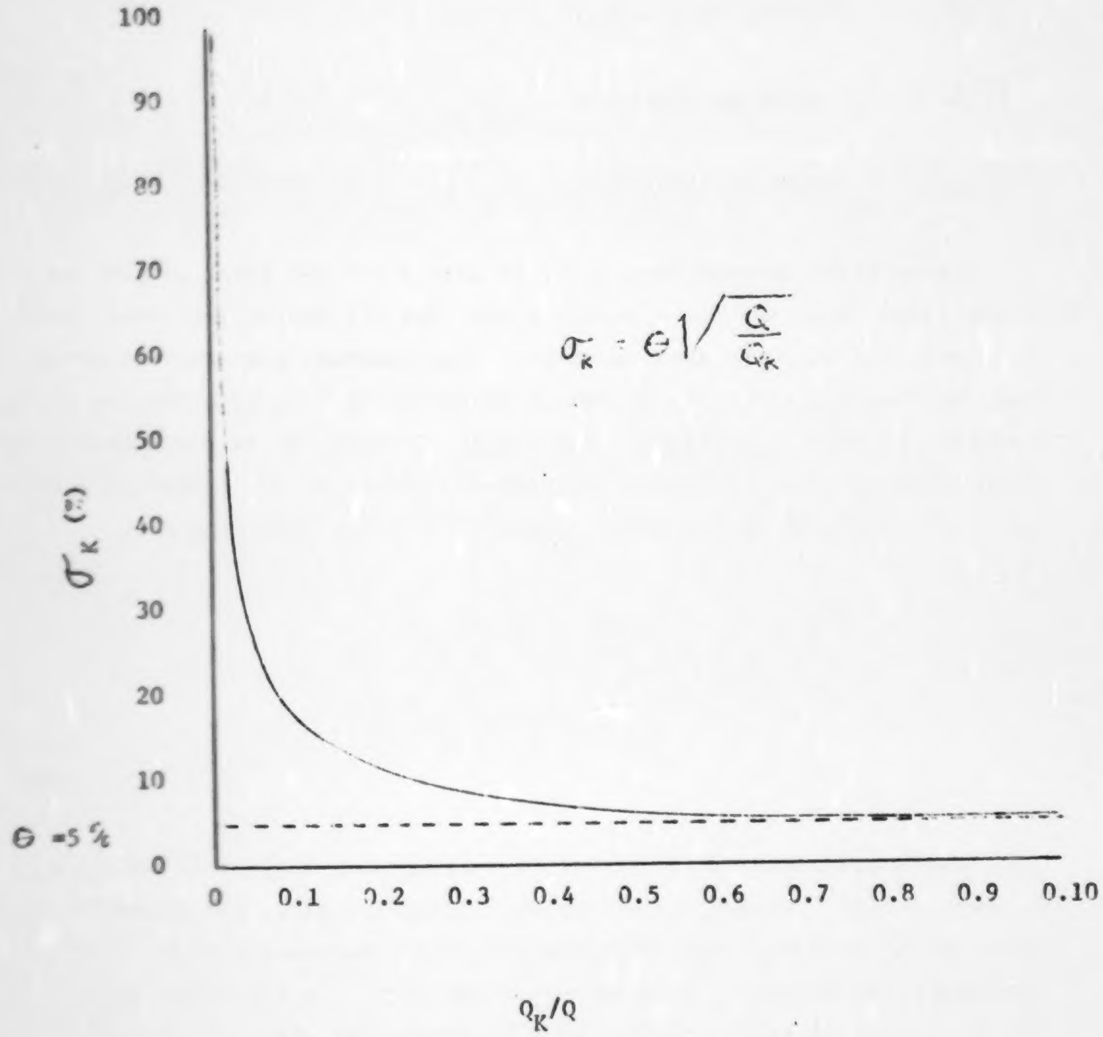
In order to illustrate the application of the technique, let Θ = 5% for the external combustion node of Figure 2.3. The allowable errors for the component branches as computed from equation (7) are as follows:

$$\sigma_1 = 5\sqrt{\frac{5070238}{3416197}} = 6.09\%$$

$$\sigma_2 = 5\sqrt{\frac{5070238}{1562142}} = 9.01\%$$

$$\sigma_3 = 5\sqrt{\frac{5070238}{89158}} = 37.70\%$$

$$\sigma_4 = 5\sqrt{\frac{5070238}{2741}} = 215.04\%$$



RELATIONSHIP BETWEEN σ_K AND Q_K/Q

Figure 2.4

The allowable errors in physical units are:

$\sigma_1 Q_1 = \pm$ 208046.39 tons/year

$\sigma_2 Q_2 = \pm$ 140748.99 tons/year

$\sigma_3 Q_3 = \pm$ 33612.56 tons/year

$\sigma_4 Q_4 = \pm$ 5894.24 tons/year

The analysis demonstrates that, to obtain a known level of precision in the total emissions for a source class, not all source subclasses need to be measured with the same precision. Furthermore, the analysis shows that the probable error of the sum of emissions is less than the sum of the probable error of the component emissions. In fact, it is the square root of the weighted sum of the squared probable errors of the components, as can be readily observed by solving equation (1) for θ to obtain

$$\theta = \sqrt{\sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \sigma_K^2} \tag{8}$$

Figure 2.4 displays the resulting relationship between σ_K and Q_K/Q in graphic form. When Q_K is a very small fraction of Q, the allowable value of σ_K is much larger than the allowable overall error θ, increasing exponentially as Q_K/Q approaches zero. On the other hand, σ_K approaches θ asymptotically as Q_K/Q approaches one. In general,

$\sigma_K \geq \Theta$, k = 1,.., N, with the equality sign holding only in the limiting case where there is only a single source subclass. Naturally, if there is a single source subclass, $Q_K = Q$ and σ_K must be equal to Θ if the latter is to be satisfied. Otherwise, the component emission errors σ_K will be allowed to have values greater than the overall emission error Θ . With respect to Figure 2.4, it is also interesting to note that the shape of the function is invariant to the value of Θ , i.e., perturbing the value of Θ would merely shift the horizontal asymptote of the curve. This conclusion has a significant practical implication, i.e., for any given value of Θ , the σ_K's can be allowed to have values greater than Θ . This conclusion has significant impact in determining the required accuracy of measurement of emission rates, and emission factors for individual source classes. In turn, these conclusions are useful in allocating resources to the determination or measurement of various emission parameters. Hierarchial application of the technique to the complete emissions data tree will result in σ_K's much greater than the grand total Θ as the computations proceed to successively lower levels of aggregation. Sample numerical analyses for complete emission inventories will be presented in the next section.

In the case where one or more of the σ_K's in a group are to be fixed by the analyst, it is shown in Appendix A that equation (7) changes to

$$\sigma_K = \Theta\sqrt{\frac{Q}{Q_K}\left(\frac{1 - D - \tilde{Q}}{1 - \tilde{Q}}\right)} \qquad (8)$$

where

$$D = \sum_{K=m+1}^{N} \left[\left(\frac{Q_K \sigma_K}{Q \theta} \right)^2 - \frac{Q_K}{Q} \right] \tag{9}$$

and

$$\tilde{Q} = \sum_{K=m+1}^{N} \frac{Q_K}{Q} \tag{10}$$

in the general case where σ_K is unknown for $k = 1, 2, \ldots, m$ and fixed for $k = m + 1, \ldots, N$. Even assuming $\sigma_k \doteq +0$ for $k = 1, \ldots, m$, there is, of course, a maximum value that σ_K can be fixed at for $k = m + 1, \ldots, N$ and still satisfy a given overall error θ. This upper bound is also shown in Appendix A to be given by the formula

$$\sigma_K = \theta \sqrt{\frac{Q}{Q_K} \left(\frac{Q}{Q - \sum_{K=1}^{m} Q_K} \right)} \tag{11}$$

These extensions of the basic weighted sensitivity analysis will provide the analyst valuable guidance in performing the hierarchial error analysis of the emissions inventory so as to retain the integrity of the allowable error at the grand total level of emissions.

CONFIDENCE LEVEL FOR THE EMISSIONS INVENTORY

The weighted sensitivity analysis technique presented in the previous section serves to compute accuracy requirements for the component parts of an emissions inventory so as to insure that a given accuracy requirement for the overall inventory is not violated. By using Chebyshev's inequality it is possible to go one step further and establish in formal probabilistic terms the confidence level for the inventory, i.e., what is in fact the probability that the actual overall error in emissions will not exceed θ .

Chebyshev's theorem (Reference 3) states that if a probability distribution has mean $\bar{Q}$ and standard deviation θ , the probability of obtaining a value which deviates from the mean by more than λ standard deviations is less than λ^{-2}. Symbolically, in percentage error terms

$$P\left(\frac{|Q-\bar{Q}|}{Q} > \lambda\theta\right) < \frac{1}{\lambda^2} \qquad \textbf{(12)}$$

where Q is the measured grand total emissions, as before. It is important to note that Chebyshev's result is distribution-free. In other words, inequality (12) applies regardless of what probability distribution is associated with the emissions data. This is critically important because the actual probability distributions of the various emissions are generally unknown.

Letting $\alpha = \lambda\theta$, inequality (12) becomes

$$P\left(\frac{|Q-\bar{Q}|}{Q} > \alpha\right) < \frac{\theta^2}{\alpha^2} \tag{13}$$

and the fraction θ^2/α^2 gives a percentage confidence level for the inventory, i.e., the probability that the actual percentage error exceeds α is less than $c = \theta^2/\alpha^2$. As a numerical example, if it is desired to attain a 95% confidence level that the percentage emissions error will be within a 20% interval of the true value, then setting

$$\theta = \alpha\sqrt{c} = 0.20\sqrt{1-0.95} = 4.47\%$$

and applying the weighted sensitivity analysis technique to compute the σ_K's results in a set of precision requirements which, if satisfied, insure that the 95% confidence level for the emissions inventory has been attained. Using the same technique, Table 2-1 summarizes the required value

Confidence Level

Acceptance Internal

1-C α	90%	95%	99%
5%	1.58%	1.12%	0.5%
10%	3.16%	2.24%	1.0%
20%	6.32%	4.47%	2.0%

Table 2.1 Values of θ for selected pairs (α,1-C)

of for selected trade-offs between confidence level and accuracy of the for selected trade-offs between confidence level and accuracy of the emissions inventory. For example, Θ must be set at 2.24% to attain 95% confidence level for the overall inventory error to be within 10%, 6.32% for 90% assurance of it being within 20%, etc.

In summary, the analysis of random error in emissions data should be undertaken as a two-step procedure: first, establish the desired value of the overall allowable error Θ as a trade-off between confidence level and acceptable error interval, by means of Chebyshev's theorem; second, compute the required values for all component errors σ_K so as to preserve the integrity of Θ, using the weighted sensitivity analysis technique.

Section III

NUMERICAL ANALYSES

This section presents a sample numerical analysis for a complete emissions data tree, using the Ohio State Emissions Report with emissions as of February 23, 1973 as sample data. The discussion will cover numerical analysis of both the nominal hierarchy or tree (as in Figures 2.1 and 2.2) and some alternative trees.

During the project, weighted sensitivity analyses were run for each of the nine values of overall error θ in Table 2.1, and for each of the following summaries: county emissions report (Franklin County, Ohio), AQCR emissions report (Metropolitan Columbus, Ohio), state emissions report (Ohio) and nationwide emissions report (United States). Complete numerical analyses for the nationwide emissions report (with emissions as of April 19, 1973) using three different values of θ are reproduced in Appendix B of this final report. Other numerical analyses conducted during the project are available as computer printouts. The annotated numerical analysis given in this section is presented to illustrate the application of the techinique from the analyst's viewpoint.

ANALYSIS OF THE STANDARD TREE

A complete weighted sensitivity analysis for the Ohio State Emissions Report (with emissions as of February 23, 1973) is tabulated in Table 3.1.

Table 3.1 Weighted Sensitivity Analysis of Ohio State Emissions Report with $\epsilon = 5\%$

```
OHIO
****************
STATE EMISSIONS REPORT (RUN DATE: APRIL 3, 1973)
EMISSIONS AS OF FEBRUARY 23, 1973
50773
17  4  19.6

SOURCE HIERARCHY


SOURCE CLASS AND SUBCLASSES
                                              WEIGHTED SENSITIVITY ANALYSIS

                           PARTICULATES       SULFUR OXIDES      NITROGEN OXIDES     HYDROCARBONS      CARBON MONOXIDE
                         TONS/YR   SIGMA    TONS/YR   SIGMA    TONS/YR   SIGMA    TONS/YR   SIGMA    TONS/YR   SIGMA
                                  PERCENT            PERCENT            PERCENT            PERCENT             PERCENT
233 GRAND TOTAL          2094254    5.00    3266037    5.00    1428729    5.00    1271409    5.00   13744109    5.00

235 AREA SOURCES          492906   10.31     401632   14.26     556745    8.01    1078272    5.43    4277085    8.96
236 POINT SOURCES        1601348    5.72    2864405    5.34     871984    6.40     193137   12.83    9467024    6.02
```

Table 3.1

SOURCE HIERARCHY [1 .]

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
236 POINT SOURCES	1601348	5.72	2864405	5.34	871984	6.40	193137	12.83	9467024	6.02
11 FUEL COMBUSTION	626684	9.14	2608288	5.60	507233	8.39	11700	52.12	26977	112.86
130 INDUSTRIAL PROCESS (POINT)	968858	7.35	251403	18.02	363863	9.91	177135	13.40	9427514	6.04
146 SOLID WASTE DISPOSAL	5806	94.96	4714	131.61	887	200.67	4302	85.96	12533	165.58
231 OTHER (POINT)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY

11 FUEL COMBUSTION [1 .1]

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
129 POINT SOURCES	626684	9.14	2608288	5.60	507233	8.39	11700	52.12	26977	112.86
13 EXTERNAL COMBUSTION	626672	9.14	2608277	5.60	506990	8.39	11371	52.87	26907	113.00
103 INTERNAL COMBUSTION (POINT)	12	2088.79	12	2608.49	243	383.39	329	310.82	70	2215.54
126 OTHER (POINT)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY [1 . 2]

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
130 INDUSTRIAL PROCESS (POINT)	968858	7.35	251403	- 18.02	363863	9.91	177135	13.40	9427514	6.04
132 CHEMICAL MANUFACTURING	6404	90.42	11312	84.96	2321	124.05	57419	23.53	25691	115.65
133 FOOD/AGRICULTURAL	6121	92.49	0	0.00	0	0.00	385	287.33	16	4369.10
134 PRIMARY METAL	388813	11.60	22461	60.29	215	407.59	21629	38.33	6269525	7.40
135 SECONDARY METALS	14614	59.85	4517	134.45	13	1657.58	188	411.18	218705	39.64
136 MINERAL PRODUCTS	406520	11.35	10476	88.28	753	217.79	12	1627.50	35	3133.24
137 PETROLEUM INDUSTRY	139711	19.36	202171	20.10	360543	9.95	43623	26.99	2907030	10.87
138 WOOD PRODUCTS	1395	193.73	465	419.04	0	0.00	0	0.00	6510	229.74
139 EVAPORATION	0	0.00	0	0.00	0	0.00	50607	25.06	0	0.00
140 METAL FABRICATION	2531	143.83	0	0.00	19	1371.10	4	2018.92	0	0.00
141 LEATHER PRODUCTS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
142 TEXTILE MANUFACTURING	11	2181.67	0	0.00	0	0.00	2858	105.46	0	0.00
143 INPROCESS FUEL	0	0.00	0	0.00	0	0.00	361	296.73	0	0.00
144 OTHER/NOT CLASIED	2739	138.26	0	0.00	0	0.00	50	797.31	0	0.00

SOURCE HIERARCHY [1 .3]

146 SOLID WASTE DISPOSAL

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
190 POINT SOURCES	5806	94.96	4714	131.61	887	200.67	4302	85.96	12533	165.58
148 GOVERNMENT (POINT)	4378	109.35	628	360.58	667	231.41	3343	97.51	8766	197.98
157 COMMERCIAL-INSTITUTIONAL	187	529.13	23	1384.16	32	1056.50	210	389.05	1147	547.33
171 INDUSTRIAL	1241	205.40	4063	141.76	188	435.88	749	206.00	2620	362.14
187 OTHER (POINT)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 1.1.1

13 EXTERNAL COMBUSTION

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
102 POINT SOURCES	626672	9.14	2608277	5.60	506990	8.39	11371	52.87	26907	113.00
22 ELEC GENERATION (POINT)	343145	12.35	1989919	6.41	385364	9.63	5517	75.90	17645	139.55
35 INDUSTRIAL FUEL	272433	13.86	597857	11.69	117456	17.44	5604	75.31	8459	201.54
71 COMM-INSTITUTIONAL FUEL	11095	68.69	20501	63.11	4170	92.55	250	356.57	803	654.14
99 OTHER (POINT)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.1.2

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
103 INTERNAL COMBUSTION (POINT)	12	2088.79	12	2608.49	243	383.39	329	310.82	70	2215.54
104 ELECTRIC GENERATION	4	3617.88	3	5216.99	27	1150.17	0	0.00	0	0.00
110 INDUSTRIAL FUEL	9	2411.92	8	3194.74	216	406.65	329	310.82	70	2215.54
117 COMM-INSTITUTIONAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
121 ENGINE-TESTING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 1.3.1

146 SOLID WASTE DISPOSAL

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
148 GOVERNMENT (POINT)	4378	109.36	628	360.58	667	231.41	3343	97.51	8766	197.98
149 MUNICIPAL INCINERATION	3899	115.88	599	369.20	487	270.82	2445	114.02	6221	235.02
150 OPEN BURNING	479	330.61	30	1649.76	180	445.46	898	188.14	2545	367.44
151 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.3.2

146 SOLID WASTE DISPOSAL
157 COMMERCIAL-INSTITUTIONAL

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
170 POINT SOURCES	187	529.13	23	1884.16	32	1056.50	210	389.05	1147	547.33
158 ON SITE INCINERATION	154	583.07	23	1884.16	29	1109.80	202	396.68	1052	571.51
161 OPEN BURNING	32	1279.12	0	0.00	4	2988.24	8	1993.28	95	1901.81
164 APARTMENT	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
166 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.3.3

146 SOLID WASTE DISPOSAL
171 INDUSTRIAL

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
186 POINT SOURCES	1241	205.40	4063	141.76	188	435.88	749	206.00	2620	362.14
172 ON SITE INCINERATION	253	454.91	4050	141.99	74	694.75	209	389.98	526	808.23
175 OPEN BURNING	975	231.73	13	2500.16	113	562.22	537	243.29	2078	406.64
178 AUTO BODY INCINERATION	13	2006.84	0	0.00	1	5976.47	3	3255.01	16	4634.13
	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 1.1.1.1

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
	WEIGHTED SENSITIVITY ANALYSIS									
22 ELEC GENERATION (POINT)	343145	12.35	1989919	6.41	385364	9.63	5517	75.90	17645	139.55
23 ANTHRACITE COAL	657	282.29	6353	113.37	855	204.39	13	1563.66	488	839.11
24 BITUMINOUS COAL	342366	12.37	1982733	6.42	380923	9.68	5234	77.93	17154	141.53
25 LIGNITE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
26 RESIDUAL OIL	18	1705.49	426	437.80	3699	98.27	7	2130.90	0	0.00
27 DISTILLATE OIL	14	1933.84	403	450.12	794	212.10	15	1455.68	0	0.00
28 NATURAL GAS	90	762.72	3	5216.99	2423	121.41	249	357.28	2	10000.00
29 PROCESS GAS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
30 COKE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
31 BAGASSE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
32 SOLID WASTE/COAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
33 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.1.1.2

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION
35 INDUSTRIAL FUEL

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
	WEIGHTED SENSITIVITY ANALYSIS									
70 POINT SOURCES	272433	13.86	597857	11.69	117456	17.44	5604	75.31	8459	201.54
36 ANTHRACITE COAL	8	2558.23	739	332.40	63	752.96	1	5637.84	36	3089.42
39 BITUMINOUS COAL	262861	14.11	566189	12.01	91900	19.71	3368	97.15	8385	202.43
42 LIGNITE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
44 RESIDUAL OIL	1191	209.67	12260	81.61	3223	105.27	152	457.29	9	6178.84
47 DISTILLATE OIL	104	709.53	314	509.94	1087	181.27	54	767.21	3	10000.00
50 NATURAL GAS	1638	178.78	25	1807.22	19340	42.98	2020	125.44	17	4495.77
53 PROCESS GAS	6533	89.52	18324	66.75	1799	140.91	0	0.00	0	0.00
56 COKE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
59 WOOD	98	730.52	7	3415.32	44	900.99	9	1879.28	9	6178.84
62 LIQUID PETROL GAS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
64 BAGASSE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
66 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 1.1.1.3

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION
71 COMM-INSTITUTIONAL FUEL

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
98 POINT SOURCES	11095	68.69	20501	63.11	4170	92.55	250	356.57	803	654.14
72 ANYHRACITE COAL	32	1279.12	1295	251.10	65.	741.29	2	3986.55	108	1783.68
75 BITUMINOUS COAL	10909	69.28	18396	66.62	3613	99.43	219	380.97	672	715.06
78 LIGNITE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
80 RESIDUAL OIL	100	723.58	690	344.00	261	369.93	13	1563.66	1	10000.00
83 DISTILLATE OIL	32	1279.12	119	828.34	108	575.09	6	2301.64	0	0.00
86 NATURAL GAS	22	1542.67	1	9036.09	124	536.70	9	1679.28	22	3952.00
89 WOOD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
92 LIQUID PETROL GAS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
94 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.1.2.1

11 FUEL COMBUSTION
103 INTERNAL COMBUSTION (POINT)

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
104 ELECTRIC GENERATION	4	3617.88	3	5216.99	27	1150.17	0	0.00	0	0.00
105 DISTILLATE OIL	4	3617.88	3	5216.99	27	1150.17	0	0.00	0	0.00
106 NATURAL GAS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
107 DIESEL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
108 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 1.1.2.2

11 FUEL COMBUSTION
103 INTERNAL COMBUSTION (POINT)

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
110 INDUSTRIAL FUEL	9	2411.92	8	3194.74	216	406.65	329	310.82	70	2215.54
111 DISTILLATE OIL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
112 NATURAL GAS	0	0.00	0	0.00	1	5976.47	0	0.00	0	0.00
113 GASOLINE	5	3235.93	0	0.00	101	594.68	317	316.65	0	0.00
114 DIESEL FUEL	4	3617.88	8	3194.74	115	557.31	11	1699.87	70	2215.54
115 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.1.2.3

11 FUEL COMBUSTION
103 INTERNAL COMBUSTION (POINT)

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
117 COMM-INSTITUTIONAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
118 DIESEL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
119 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.1.2.4

11 FUEL COMBUSTION
103 INTERNAL COMBUSTION (POINT)

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
121 ENGINE-TESTING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
122 AIRCRAFT	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
123 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY [2.]

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXID TONS/YR	CARBON MONOXID SIGMA PERCEN
235 AREA SOURCES	492906	10.31	401632	14.26	556745	8.01	1078272	5.43	4277085	8.9
11 FUEL COMBUSTION	417216	11.20	373186	14.79	110465	17.98	17655	42.43	48036	84.5
146 SOLID WASTE DISPOSAL	47322	33.26	3303	157.23	9564	61.11	97123	18.09	259850	36.3
191 TRANSPORTATION (AREA)	28368	42.96	25143	56.99	436715	9.04	804507	6.29	3969199	9.3
217 MISCELLANEOUS (AREA)	0	0.00	0	0.00	0	0.00	158987	14.14	0	0.0

SOURCE HIERARCHY [2.1]

11 FUEL COMBUSTION

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXID TONS/YR	CARBON MONOXID SIGMA PERCEN
128 AREA SOURCES	417216	11.20	373186	14.79	110465	17.98	17655	42.43	48036	84.5
101 AREA SOURCES	417216	11.20	373186	14.79	110465	17.98	17655	42.43	48036	84.5

SOURCE HIERARCHY [2.2]

146 SOLID WASTE DISPOSAL

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
189 AREA SOURCES	47322	33.26	3303	157.23	9564	61.11	97123	18.09	259850	36.36
153 RESIDENTIAL (AREA)	20046	51.11	601	308.59	2661	115.86	59775	23.06	173129	44.55
157 COMMERCIAL-INSTITUTIONAL	3841	116.75	359	476.91	1045	184.88	5713	74.59	13492	159.58
171 INDUSTRIAL	23435	47.27	2344	136.64	5858	78.09	31636	31.70	73230	68.5

Table 3.1

SOURCE HIERARCHY [2.3]

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
191 TRANSPORTATION (AREA)	28368	42.96	25143	56.99	436715	9.04	804507	6.29	3969199	9.30
193 LAND VEHICLES	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
194 GASOLINE	19439	51.90	11689	83.58	324499	10.49	725084	6.62	3834397	9.47
199 DIESEL	3904	115.81	8038	100.79	106078	18.35	10925	53.94	63469	73.58
204 AIRCRAFT	3146	129.00	652	353.88	1995	133.81	8725	60.36	25808	113.21
209 VESSELS	1881	166.84	4764	130.92	4143	92.85	9086	59.14	44525	87.85
215 GAS HANDLING EVAP LOSS	0	0.00	0	0.00	0	0.00	50685	25.04	0	0.00

SOURCE HIERARCHY [2.4]

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
217 MISCELLANEOUS (AREA)	0	0.00	0	0.00	0	0.00	158987	14.14	0	0.00
219 FOREST FIRE/AGRIC BURNING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
220 STRUCTURAL FIRES	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
221 COAL REFUSE BURNING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
222 SLASH BURNING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
223 FROST CONTROL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
224 SOLVENT EVAPORATION LOSS	0	0.00	0	0.00	0	0.00	158987	14.14	0	0.00
225 DUST SOURCES	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
226 DIRT ROADS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
227 DIRT AIRSTRIPS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
228 CONSTRUCTION	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
229 ROCK HANDLING/STORING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 2.1.1

13 EXTERNAL COMBUSTION

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
101 AREA SOURCES	417216	11.20	373186	14.79	110465	17.98	17655	42.43	48036	84.58
14 RESIDENTIAL FUEL (AREA)	13843	61.50	41175	44.53	15867	47.45	8822	60.02	36377	97.19
35 INDUSTRIAL FUEL	364627	11.98	261455	17.67	64275	23.57	6242	71.36	6381	232.05
71 COMM-INSTITUTIONAL FUEL	38746	35.76	70556	34.02	30323	34.32	2590	110.78	5277	255.17

SOURCE HIERARCHY 2.2.1

146 SOLID WASTE DISPOSAL

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
153 RESIDENTIAL (AREA)	20046	51.11	601	368.59	2661	115.86	59775	23.06	173129	44.55
154 ON SITE INCINERATION	14215	60.69	237	586.96	474	274.51	47383	25.90	142150	49.16
155 OPEN BURNING	5831	94.76	364	473.62	2187	127.80	12391	50.65	30978	105.32

SOURCE HIERARCHY 2.2.2

146 SOLID WASTE DISPOSAL
157 COMMERCIAL-INSTITUTIONAL

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
169 AREA SOURCES	3841	116.75	359	476.91	1045	184.88	5713	74.59	13492	159.58
158 ON SITE INCINERATION	1896	166.17	237	586.96	316	336.20	1580	141.84	3160	329.75
161 OPEN BURNING	1945	164.07	122	818.09	729	221.35	4133	87.70	10332	182.36

Table 3.1

SOURCE HIERARCHY 2.2.3

146 SOLID WASTE DISPOSAL
171 INDUSTRIAL

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
165 AREA SOURCES	23435	47.27	2344	136.64	5858	78.09	31636	31.70	73230	68.50
172 ON SITE INCINERATION	14062	61.02	1758	215.51	2344	123.44	11718	52.08	23437	121.08
175 OPEN BURNING	9373	74.74	586	373.28	3515	100.81	19917	39.95	49793	83.07

SOURCE HIERARCHY [illegible]

191 TRANSPORTATION (AREA)
193 LAND VEHICLES

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
194 GASOLINE	19439	51.90	11609	83.58	324493	10.49	725084	6.62	3834397	9.47
195 LIGHT VEHICLES	16413	56.48	9848	91.06	235250	12.32	513303	7.87	2856158	10.97
196 HEAVY VEHICLES	2001	161.76	1201	260.74	66706	23.14	140950	15.02	590138	24.13
197 OFF HIGHWAY	1025	226.01	640	357.18	22543	39.81	70832	21.18	388101	29.75

SOURCE HIERARCHY 2.3.2

191 TRANSPORTATION (AREA)
193 LAND VEHICLES

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
199 DIESEL	3904	115.81	8038	100.79	106078	18.35	10925	53.94	63469	73.58
200 HEAVY VEHICLES	2167	155.44	4334	137.26	61404	24.12	6140	71.95	36120	97.53
201 OFF HIGHWAY	1550	183.79	3219	159.26	44115	28.45	4412	84.88	26827	113.17
202 RAIL	186	530.55	485	410.31	559	252.78	373	291.92	522	811.32

Table 3.1

SOURCE HIERARCHY 2.3.3

191 TRANSPORTATION (AREA)

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
204 AIRCRAFT	3146	129.00	652	353.88	1995	133.81	8725	60.36	26808	113.21
205 MILITARY	993	229.62	190	655.55	477	273.64	2310	117.30	2480	372.22
206 CIVIL	616	291.54	122	818.09	556	253.46	2726	107.98	15579	148.51
207 COMMERCIAL	1537	184.56	341	489.33	962	192.69	3689	92.82	8749	198.18

SOURCE HIERARCHY 2.3.4

191 TRANSPORTATION (AREA)

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
209 VESSELS	1881	166.84	4764	130.92	4143	92.85	9088	59.14	44525	87.85
210 BITUMINOUS COAL	1177	210.91	2942	166.59	177	449.22	1177	164.33	5290	254.71
211 DIESEL FUEL	495	325.22	1238	251.78	1486	155.04	990	179.18	1387	497.73
212 RESIDUAL OIL	108	696.26	471	416.36	283	355.26	14	1506.78	1	10000.00
213 GASOLINE	100	723.58	62	1147.58	2198	127.48	6906	67.84	37842	95.29

Table 3.1

```
SOURCE HIERARCHY     2.1.1.1

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION


SOURCE CLASS AND SUBCLASSES                              WEIGHTED SENSITIVITY ANALYSIS

                              PARTICULATES       SULFUR OXIDES      NITROGEN OXIDES     HYDROCARBONS      CARBON MONOXIDE
                            TONS/YR   SIGMA    TONS/YR   SIGMA    TONS/YR   SIGMA    TONS/YR   SIGMA    TONS/YR   SIGMA
                                     PERCENT            PERCENT            PERCENT            PERCENT            PERCENT

14 RESIDENTIAL FUEL (AREA)    13843    61.50     41175    44.53     15867    47.45      8822    60.02     36377    97.19

15 ANTHRACITE COAL              330   398.32       141   760.98        99   600.66        83   618.83      2974   339.91
16 BITUMINOUS COAL             6103    92.62     28217    53.79       915   197.58      6103    72.17     27464   111.85
17 DISTILLATE OIL              2321   150.19     12663    80.30      2785   113.25       696   213.70      1160   544.25
18 RESIDUAL OIL                   0     0.00         0     0.00         0     0.00         0     0.00         0     0.00
19 NATURAL GAS                 4495   107.92       142   758.29     11830    54.95      1893   129.58      4732   269.47
20 WOOD                         594   296.89        12  2606.49       237   388.21        47   822.36        47  2703.83


SOURCE HIERARCHY          2.1.1.2

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION
35 INDUSTRIAL FUEL


SOURCE CLASS AND SUBCLASSES                              WEIGHTED SENSITIVITY ANALYSIS

                              PARTICULATES       SULFUR OXIDES      NITROGEN OXIDES     HYDROCARBONS      CARBON MONOXIDE
                            TONS/YR   SIGMA    TONS/YR   SIGMA    TONS/YR   SIGMA    TONS/YR   SIGMA    TONS/YR   SIGMA
                                     PERCENT            PERCENT            PERCENT            PERCENT            PERCENT

69 AREA SOURCES              364627    11.98    261455    17.67     64275    23.57      6242    71.36      6381   232.05

36 ANTHRACITE COAL                0     0.00         0     0.00         0     0.00         0     0.00         0     0.00
39 BITUMINOUS COAL           362393    12.02    258263    17.72     47549    27.41      3170   100.13      6340   232.80
44 RESIDUAL OIL                 935   236.63      3149   161.03      3741    97.71       187   412.28        12  5351.03
47 DISTILLATE OIL                 0     0.00         0     0.00         0     0.00         0     0.00         0     0.00
50 NATURAL GAS                 1298   200.84        43  1377.99     12984    52.45      2885   104.96        29  3442.15
53 PROCESS GAS                    0     0.00         0     0.00         0     0.00         0     0.00         0     0.00
56 COKE                           0     0.00         0     0.00         0     0.00         0     0.00         0     0.00
59 WOOD                           0     0.00         0     0.00         0     0.00         0     0.00         0     0.00
```

Table 3.1

SOURCE HIERARCHY 2.1.1.3

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION
71 COMM-INSTITUTIONAL FUEL

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
97 AREA SOURCES	38746	36.76	70556	34.02	30323	34.32	2590	110.78	5277	255.17
72 ANTHRACITE COAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
75 BITUMINOUS COAL	32816	39.94	52059	39.60	5866	78.03	1275	157.89	4591	273.57
80 RESIDUAL OIL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
83 DISTILLATE OIL	5345	98.97	18479	66.47	21381	40.87	1069	172.43	71	2199.88
86 NATURAL GAS	585	299.16	18	2129.83	3077	107.74	246	359.46	615	747.46
89 WOOD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

The table displays the σ_K's which result from setting $\theta = 5\%$ for each of the five classes of air pollutants. For clarity of presentation, Table 3.1 is structured so as to give the Q_K's and σ_K's in adjacent columns for the five pollutants, with the source breakdown on the left following the standard NEDS categorization of emissions sources as shown in Figure 2.1 and Figure 2.2. Each grouping of emission sources in the table is labeled by line number and title (refer to Figure 2.1) as well as by node (refer to Figure 2.2).

These numerical results fully illustrate the characteristics of the weighted sensitivity analysis as discussed in the previous section. Starting at the grand total (highest) level of aggregation, the formula of equation (7) is applied in a hierarchial fashion, working through nodes and branches down to elementary emissions data. It is possible to appreciate a significant relaxation of precision requirements as the analysis progresses from top to bottom of the hierarchy. It is also possible to appreciate the effect of the weightings as allowable errors are allocated in proportion to the relative dominance of the various emissions in any given group. With reference to the relationship between the weightings Q_K/Q and the allowable errors σ_K, it is possible to observe in the results the well-behaved asymptotic character of the technique, as anticipated in Figure 2.4. Any σ_K approaches its corresponding   when the ratio Q_K/Q approaches one; see, for example, the allowable error for sulfur oxides emissions in source hierachy [1.], the allowable error for particulate emissions in source hierarchy [1.3.2], and of course any of the cases where there is a single nonzero subclass of emissions in a given group. On the other hand, any σ_K increases exponentially to the assumed maximum of 10,000% when Q_K/Q approaches zero; this is the case, for example, in the computation of the allowable error for carbon monoxide in source hierarchy [2.3.4]. In general, $\theta \leq \sigma_K \leq$ 10,000 for any value of   (10,000% is an arbitrary upper bound on σ_K).

ANALYSIS OF ALTERNATIVE TREES

There are two types of structural changes which can be of interest in working with the emissions data tree of Figure 2.2. On the other hand, it may be desired to eliminate a node of the tree. For example, the fuel combustion subtrees of Figure 2.2 could be restructured by classes of fuels, thus eliminating two intermediate nodes and permitting a direct analysis of fuel combustion emissions broken down by type of fuel combusted regardless of what activity the fuel was consumed for. On the other hand, it may be convenient to aggregate the branches of a given node into a smaller number of branches. This could be useful, for example, to reduce forecasting effort by consolidating into a single forecast sources with the smallest emissions so that the new error requirement can still be satisfied.

The first case is illustrated in Figure 3.1 and the numerical results are summarized in Table 3.2 for the modified point sources subtree. In order to obtain the σ_K's of Table 3.2, the Q_K for each of the fifteen types of fuels first had to be computed by summing the emission contributions from usage of that fuel in all branches of the subtree. The results are indicative of the predominance of bituminous coal users as the source of air pollutants released through fuel combustion, and therefore the need for better forecasting and control of these sources.

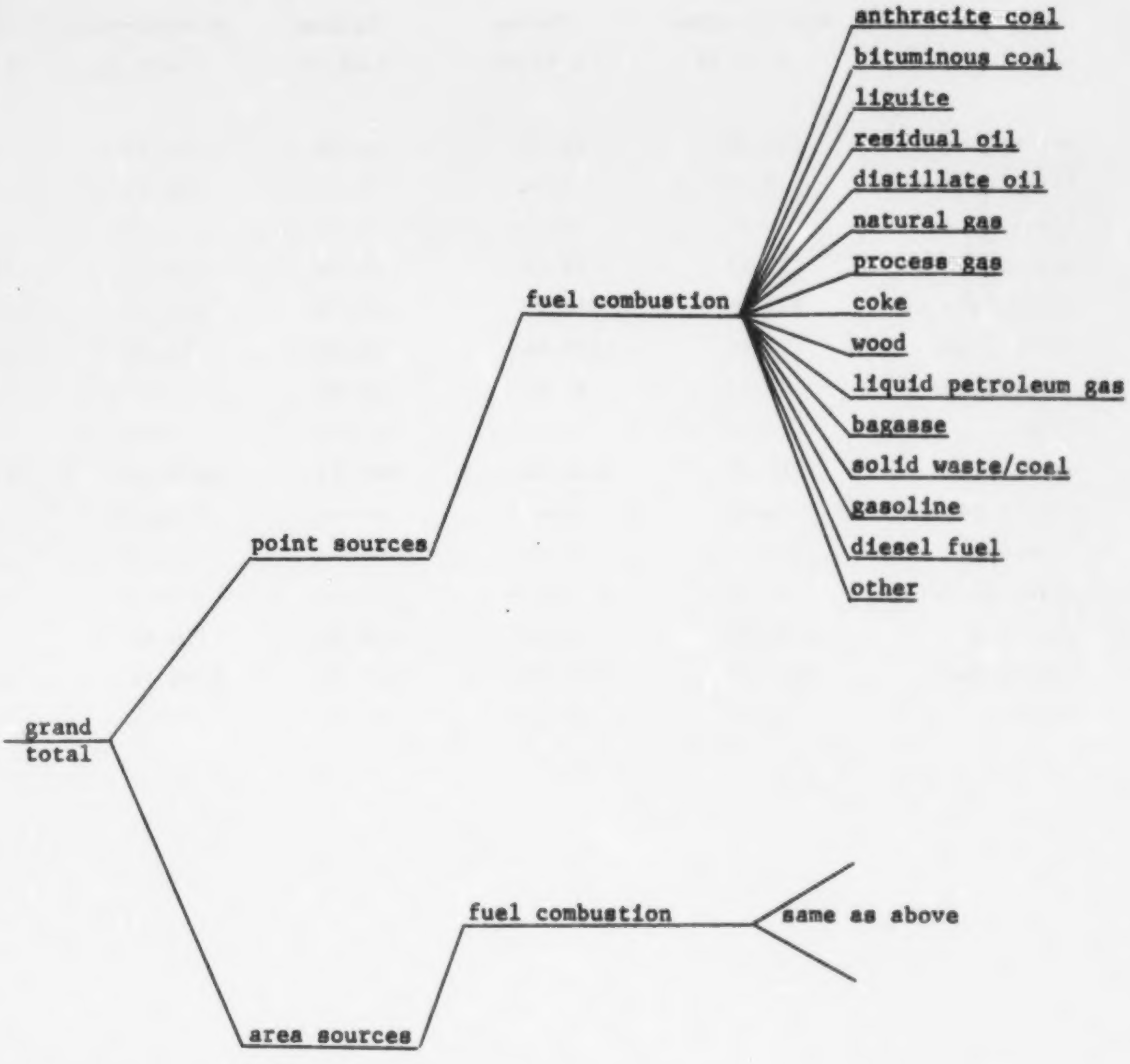

grand total
point sources
fuel combustion
anthracite coal
bituminous coal
liguite
residual oil
distillate oil
natural gas
process gas
coke
wood
liquid petroleum gas
bagasse
solid waste/coal
gasoline
diesel fuel
other
area sources
fuel combustion
same as above

Figure 3.1 Fuel combustion subtrees restructured by classes of fuels

	Particulates θ =9.14	Sulfur Oxides θ =5.60	Nitrogen Oxides θ =8.39	Hydrocarbons θ =52.12	Carbon Monoxide θ =112.86
antracite coal	274.06	98.75	190.58	1409.35	737.34
bituminous coal	9.22	5.64	8.65	60.02	114.49
liguite	-----	-----	-----	-----	-----
residual oil	199.98	78.19	96.26	429.84	5861.77
distillate oil	583.06	312.23	133.08	650.95	10000.00
natural gas	172.96	1679.44	40.39	118.11	2894.92
process gas	89.52	66.81	140.88	-----	-----
coke	-----	-----	-----	-----	-----
wood	730.90	3418.35	900.82	1879.13	6178.84
liquid pet/gas	-----	-----	-----	-----	-----
bagasse	-----	-----	-----	-----	-----
solid waste/coal	-----	-----	-----	-----	-----
gasoline	3235.83	-----	594.57	316.62	-----
diesel fuel	3617.77	3197.57	557.21	1699.74	2215.54
other	-----	-----	-----	-----	-----

Table 3.2 Weighted Sensitivity Analysis (σ_K) of Point Fuel Combustion Subtrees restructured by classes of fuels

The second case can be illustrated with reference to source hierarchy [1.2] in Table 3.1, particularly the carbon monoxide column. The dominant Q_K's correspond to primary metals (6269525 tons/yr) and the petroleum industry (2907030 tons/yr). Consolidating carbon monoxide emissions from all other industrial processes into a single group yields the following results:

	Q_K (tons/yr)	σ_K (%)
primary metals	6269525	7.40
petroleum industry	2907030	10.87
other industrial processes	250957	37.02

The results above were computed, of course, using the same θ=6.04%. The value of σ_K for the aggregated "other industrial processes" is not very restrictive and could be an indication that detailed forecasts of carbon monoxide emissions for specific industries other than primary metals and petroleum are not necessary to preserve the integrity of the emissions inventory. Generally speaking, forecasting effort can be reduced by regrouping the source classes with the smallest emissions into one or more classes; however, this policy should be applied with some discretion in order to have groups or classes which are meaningful and which can be successfully forecast.

Section IV

WEIGHTED SENSITIVITY ANALYSIS PROGRAM (WSAP)

This section documents the software developed to implement the weighted sensitivity analysis technique. The program provides a means to evaluate (hierarchially) the maximum permissible errors in emissions data for source categories when given the maximum permissible errors for the total emission inventory. The system is coded in FORTRAN IV for the IBM System/360. The material below is structured in consonance with EPS's outline for software documentation.

Program Abstract

Program Name: WSAP   Programmer: L. J. Rushbrook
Program Written for: John Bosch   Section/Branch: National Air Data
Language: Fortran IV   Size: 66K
Normal Execution Time: 7 secs for summary (state, county) Class A
Input: Control Cards 1, Data Cards 0, Tape: 1, Disk: 0

Explanation: The single control card contains the percent error of the total emission (Theta) for each of the five pollutants. The input tape is a NEDS print tape.

Function: To provide a means of evaluating the maximum allowable error in emission data (Sigma) for source categories when given the maximum allowable error for the total emission inventory (Theta). The techniques of weighted sensitivity analysis are employed.

Output: Cards 0, Tape 0, Disk 0, Printer 1

Explanation: The "Weighted Sensitivity Analysis Program" report is printed according to the hierarchical structure of the NEDS report and lists the tons of emission (QK), the percent of allowable error and the amount of allowable error for each pollutant.

Programmed Diagnostics:

RUN TERMINATED: Invalid control card, invalid tape, tape read error.
SUMMARY PROCESSING TERMINATED: Input line not acceptable to program, negative pollutant field on input.

RUN DESCRIPTION:

This program provides a means to evaluate the maximum permissable errors in emission data for source categories when given the maximum permissable error for the total Emission Inventory. The techniques of weighted sensitivity analysis are employed.

The system is coded in Fortran IV for the IBM System 360.

The program reads the "National Emissions Data System" print tape, stores the entire amount of data for one report (state, county) in memory, and under the control of a driver table selects the lines of the report to calculate the allowable errors (σ_K) and the amount of allowable error ($\sigma_K Q_K$) for each pollutant. The output is according to the hierarchical structure of the NEDS report that is designed into the Driver Table and lists the amount (Q), the percent of allowable error sigma (σ_K) and the amount of allowable error ($\sigma_K x Q_K$) for each pollutant. The formula used for the computation is:

$$\sigma_K = \theta\sqrt{Q/Q_K}$$

where σ_K = percent allowable error for a given source
θ = percent allowable error for total emission
Q_K = amount of emissions for a given source
$Q = \sum Q_K$ for a particular category.

Method:

Figure 1 and 2 in Section 2 describe the overall system flow and the General Program flow.

A. Initialization of the Driver Table (IDRIVR)

At compile time the Driver Table is initialized. This table (IDRIVR) determines the hierarchical level for processing by selecting the lines of data to be processed from the standard National Emissions Data System input tape. The table contains values that control processing actions by specifying hierarchical headings, source class labels and references to data for processing within each hierarchy.

The Driver table is a series of sub-tables which correspond to one hierarchical level or sublevel. One sub-table thus represents the data to process for a given Theta (θ or σ). There are 33 sub-tables within IDRIVR. Normally, all 33 subtables will be used to process each state or county.

The contents of IDRIVR is a continuous stream of 3 digit numbers containing indicators and line numbers related to the standard "National Emissions Data System" report.

The indicators are of two types. One type is depicted by a numerical value greater than 799. The other indicator is a positional relationship within the sub-table and is a numerical count of the number of line numbers immediately following the indicator on which the program must act for this event.

See Appendix A for a layout of the Driver Table (IDRIVR) and an example of its use. A clear understanding of this table is essential to understanding the program.

B. Initialization of the Title Table

At compile time the Title Table (ITITL) is initialized to the values shown in Appendix B. It is a 2 dimensional array (8,238) containing the 32 character title of each possible line on the NEDS report. These titles are positioned precisely as they are on the NEDS report and each is identically spelled.

C. Setup

A parameter card is read which contains the maximum permissable error (θ) for each pollutant in the total emission inventory. It is a five digit number of two decimal places. Its maximum value is 999.99. These 5 theta (θ) values, one for each pollutant, are stored in array TH and are used to compute the sigmas (σ_K) of the lower levels.

Table TDATA is set to 0. This table will contain the amount fields to be read from tape, the calculated allowable errors (σ_K) and its allowable amounts ($\sigma_K \cdot QK$).

D. Read One NEDS State (county)

The NEDS tape is read until the first line is found. Each record is scanned until the words "National Emissions Data System" is found and this record or line is assigned line number 1. All succeeding lines are assigned the values 2-237. Blank lines are ignored.

Lines 1-6 are stored as read in IHEAD and used as is for the header of the report.

Lines 8, 9, 10 contain the columnar headings for the 5 pollutants and are stored in IPOLL. Only the 13 characters each of pollutant name are stored.

Lines 11-237 constitute data lines and are used to build the amount (QK) field of table TDATA.

Since the program which generates the NEDS tape suppresses (fails to output) all lines in which the 5 pollutant amounts are each zero, the lines of data on the NEDS tape will rarely equal the maximum number of lines (237) for a standard report. To circumvent this problem table ITITL contains all the titles for each line (11-237) of the standard NEDS report.

Progression of the read in routine is by line number (11-237) down the ITITL table. The routine will compare the standard line title in ITITL with the NEDS input line title. If equal the NEDS data for each pollutant is stored in the TDATA array, the line counter is incremented and another line is read from the NEDS tape. If unequal no data is stored (the amount fields in TDATA remain zero) the line counter is incremented and the next title in ITITL is compared to the NEDS input title. This procedure repeats itselt until line 238 is reached in the ITITL table. At this time the complete state or county has been stored in TDATA in the standard NEDS sequence and the Driver Table (IDRIVR) is ready to select lines for processing.

A change in the NEDS print program (a spelling or word repositioning change) will cause that word to never find its match in the WSAP program and insufficient data will be loaded.

To detect this possibility an error check is made at line 233, the "GRAND TOTAL" line. It is assumed that all NEDS reports have an entry for "GRAND TOTAL" (line 233). When line 233 is reached a match between NEDS and WSAP (on "GRAND TOTAL") is mandatory or WSAP will print an error, fail to process the summary (state or county) and go on to the next state. The number of errors detected during the run is printed on the first line of the last page of the run. If this number is not 0 the report is incomplete.

E. Process One State or County

The IDRIVR table contains 33 sub-tables. The program will start with sub-table 1 and continue through until table 33 or the last table is processed. The counter KTS is used to indicate the table desired (table separators encountered) and the array JTSTBL contains the start position in the IDRIVR table for each of the 33 sub-tables. The contents of KTS are used as the index for JTSTBL to determine the start point for the proper table in IDRIVR.

The first entry of the sub-table is checked for a table separator (>799) or the end of table (999). If neither, the start point for IDRIVR is stored in KJTS and is used to calculate the start points of the other key positions in the IDRIVR sub-table (see Appendix A).

The IDRIVR table is now used to drive the program. It determines what to do and which line number in the TDATA table or ITITL table to do it to. By using the indicator and line numbers in the IDRIVR table the calculation of and σ x QK begins. The line number to act on in the TDATA table (QK) is found in the IDRIVR table. This line number

(NN) in IDRIVR is used as the TDATA index [TDATA(NN)] to find the amount (QK). TDATA is a 3 dimensional array hence Sigma (σ_K) is calculated and placed next to the amount (QK) in TDATA and Sigma (σ_K) x the amount (QK) is placed next to sigma in TDATA.

After all the calculations have been made for each pollutant the report for this sub-table is printed in pollutant sequence.

The sub-table report requires the following:

1. A main header

   This consists of lines 1-7 of the NEDS report.

2. A sub-table title describing the hierarchical level of the sub-table.

   This title is obtained from the ITITL array using the offset (line numbers) found in the IDRIVR array entries IH.

3. Type of pollutant

   This is taken from line 8 of the NEDS report.

4. Theta (θ or σ) used in this calculation

   Obtained from input θ or from a σ in TDATA as directed from IDRIVR entries IDH.

5. **Labels for data lines**

These labels are taken from the ITITL array as directed by the IDRIVR table entries IL.

6. **Calculations**

Data is obtained from TDATA array as directed by the IDRVR table entries ID.

After printing the report for this sub-table the next sub-table is processed and printed. This cycle continues until all 33 sub-tables have been processed.

A new state (county) is read in from the NEDS tape and the main cycle repeats until an end of file is reached on the tape.

F. Major Program Tables

BYTES

B5 (5) 5x4 20

Stores BETA (β) for 5 pollutants.

IDRIVR (720) 720x4 2,880

A continuous stream of 3 digit numbers representing indicators and line numbers used to drive the program. Initialized at compilation. See Appendix A.

IHEAD (33, 7) 4x231 924

Contains characters 2-133 of the first 7 lines, excluding blank lines, of the NEDS report tape. The carriage control character is not stored. Format is 33A4 for each line.

BYTES

IPOLL (15, 3) 54x4 180

Stores the columnar headings for each of the 5 pollutants (lines 8, 9, 10 of NEDS report).

ITITL (8, 237) (4x8)x237) 7,584

Stores the row title for each of the 237 lines of the Standard NEDS table. Initialized at compilation. See Appendix B.

JTSTBL (50) 50x4 200

Contains the start points for each sub-table in IDRIVR. Start point is determined by the Table Separator indicator (an integer greater than 799) in the IDRIVR table.

Q5 (5) 20

Stores Q for 5 pollutants.

TDATA (3, 5, 237) 4x15x237 14,220

(data, pollutant, line number)

Contains the 3 amounts (QK, σ , σxQK) for each of the 5 pollutants for each of the 237 lines.

TH (5) 5x4 20

Stores the input theta for each pollutant.

THETA5 (5) 5x4 20

Stores active THETA (θ) for 5 pollutants.

			BYTES
TN5	(5)	5x4	20
Stores pollutant fields from NEDS tape.			
QTHETA	(5)	5x4	20
Stores (Q/100)* Theta for each active pollutant in the sub-table used in printing total line.			
		Total bytes	26,108

FORMULAE USED

The formulas utilized at the various levels in the hierarchical structure of the NEDS file are:

Q Total Emission: $Q = \sum_{K=1}^{N} QK$

Beta: $\beta = \theta \sqrt{Q}$

Sigma: $\sigma = \theta \sqrt{Q/QK} = \beta / \sqrt{QK}$

θ = Percent error contained in the total emission Q.

K = A particular source class for level.

Each pollutant (maximum of 5 per run) will have its own values for the above variables. The initial input θ applies to its pollutant at the highest level (IDRIVR table 1). The σ of the preceding level then becomes the θ for the active level.

RESTRICTIONS

The input theta (on card) must be positive and no greater than 999.99.

The maximum sigma internally generated is 10,000. Anything higher defaults to 10,000.

OPTIONS

Five input thetas must be inserted in the parameter card for use by IDRIVR Table 1. A 0.00 theta entry for a pollutant will cause that pollutant to be bypassed in processing and printing for each table.

ACCURACY

All internal calculations are made in floating point and converted to fixed point for printing.

FLOW CHARTS

art 005 **WSAP OVERALL SYSTEM FLOW**

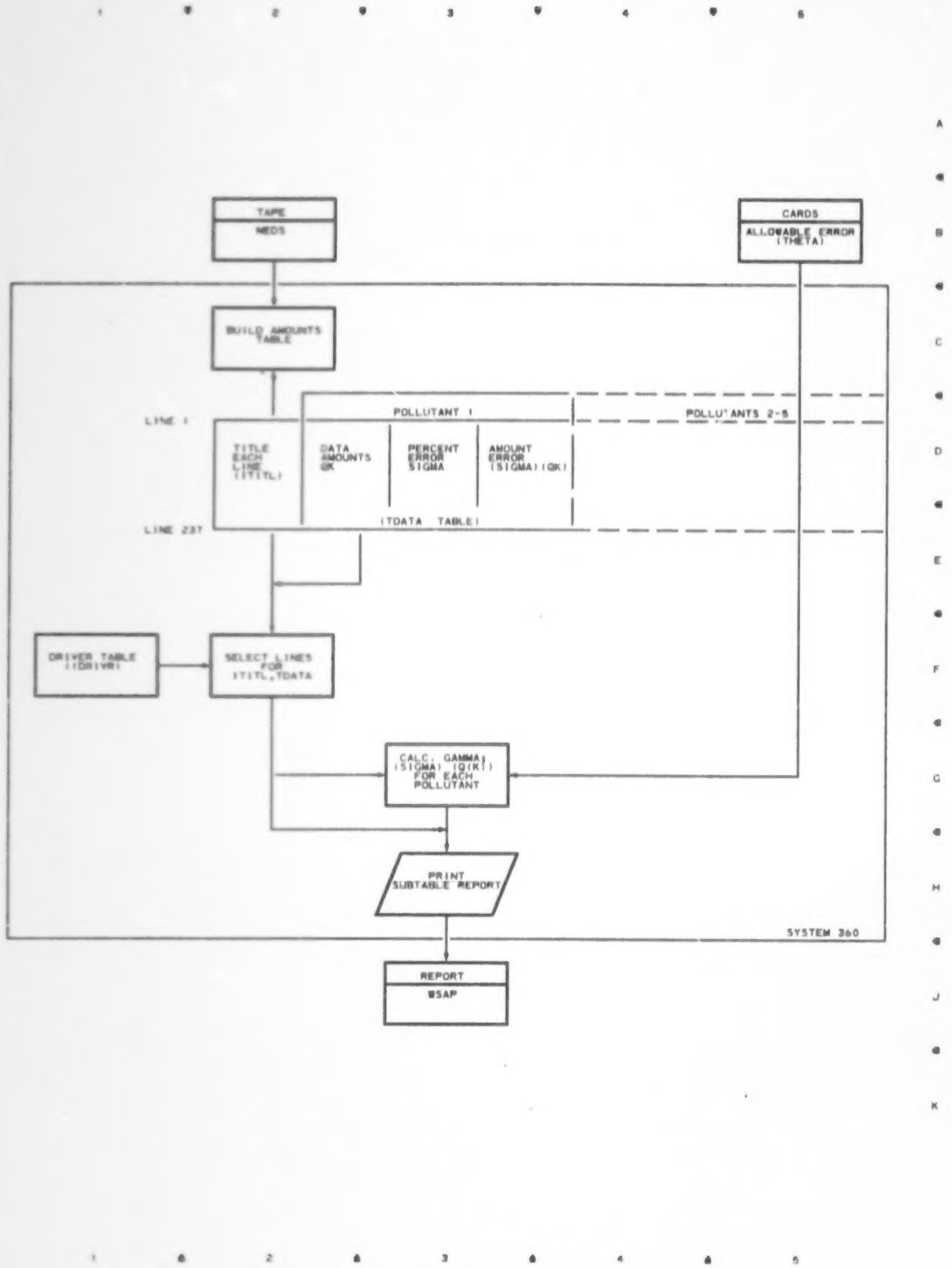

TAPE
NEDS
CARDS
ALLOWABLE ERROR (THETA)
BUILD AMOUNTS TABLE
LINE 1
POLLUTANT 1
POLLUTANTS 2-5
TITLE EACH LINE (ITITL)
DATA AMOUNTS QK
PERCENT ERROR SIGMA
AMOUNT ERROR (SIGMA)(QK)
(TDATA TABLE)
LINE 237
DRIVER TABLE (IDRIVR)
SELECT LINES FOR ITITL, TDATA
CALC. GAMMA, (SIGMA) (Q(K)) FOR EACH POLLUTANT
PRINT SUBTABLE REPORT
SYSTEM 360
REPORT
WSAP

Chart 006 GENERAL PROGRAM FLOW WEIGHTED SENSITIVITY ANALYSIS PROGRAM

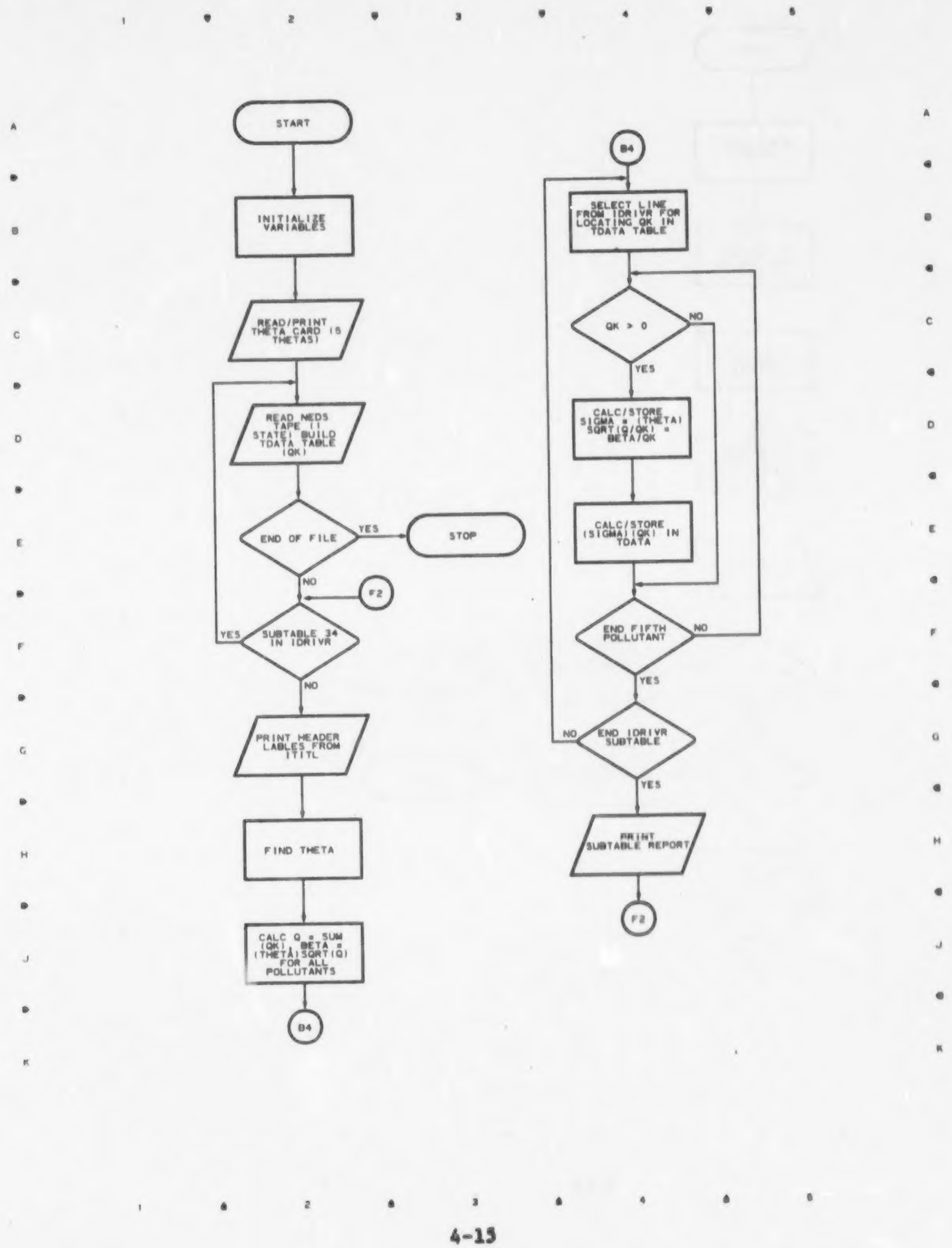

START
INITIALIZE VARIABLES
READ/PRINT THETA CARD (5 THETAS)
READ NEDS TAPE (1 STATE) BUILD TDATA TABLE (QK)
END OF FILE
YES
STOP
NO
F2
SUBTABLE 34 IN IDRIVR
YES
NO
PRINT HEADER LABLES FROM ITITL
FIND THETA
CALC Q = SUM (QK), BETA = (THETA) SQRT(Q) FOR ALL POLLUTANTS
B4
B4
SELECT LINE FROM IDRIVR FOR LOCATING QK IN TDATA TABLE
QK > 0
NO
YES
CALC/STORE SIGMA = (THETA) SQRT(Q/QK) = BETA/QK
CALC/STORE (SIGMA)(QK) IN TDATA
END FIFTH POLLUTANT
NO
YES
END IDRIVR SUBTABLE
NO
YES
PRINT SUBTABLE REPORT
F2
1
2
3
4
5
A
B
C
D
E
F
G
H
J
K

Chart 007 WSAP (SHEET 1 OF 7)

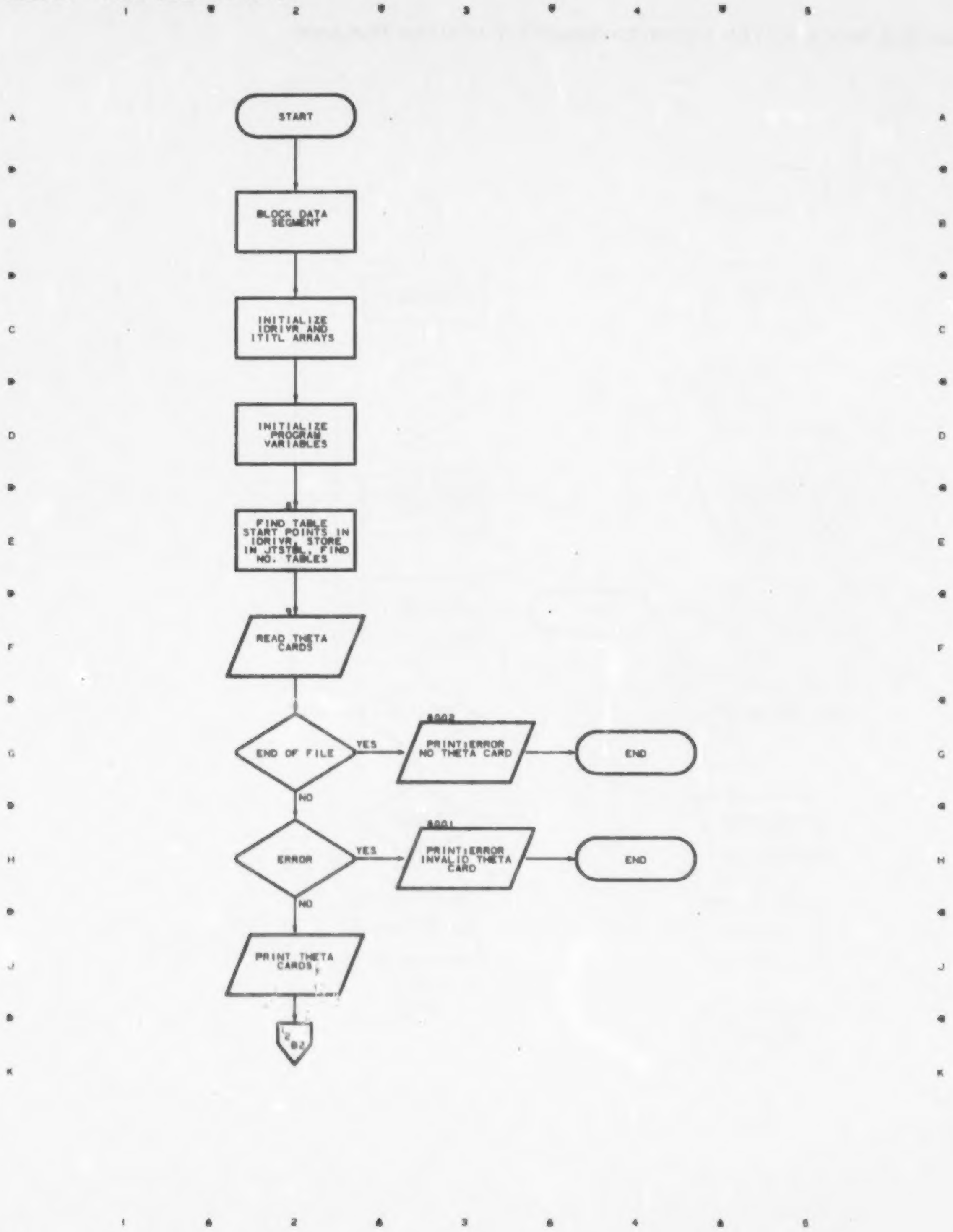
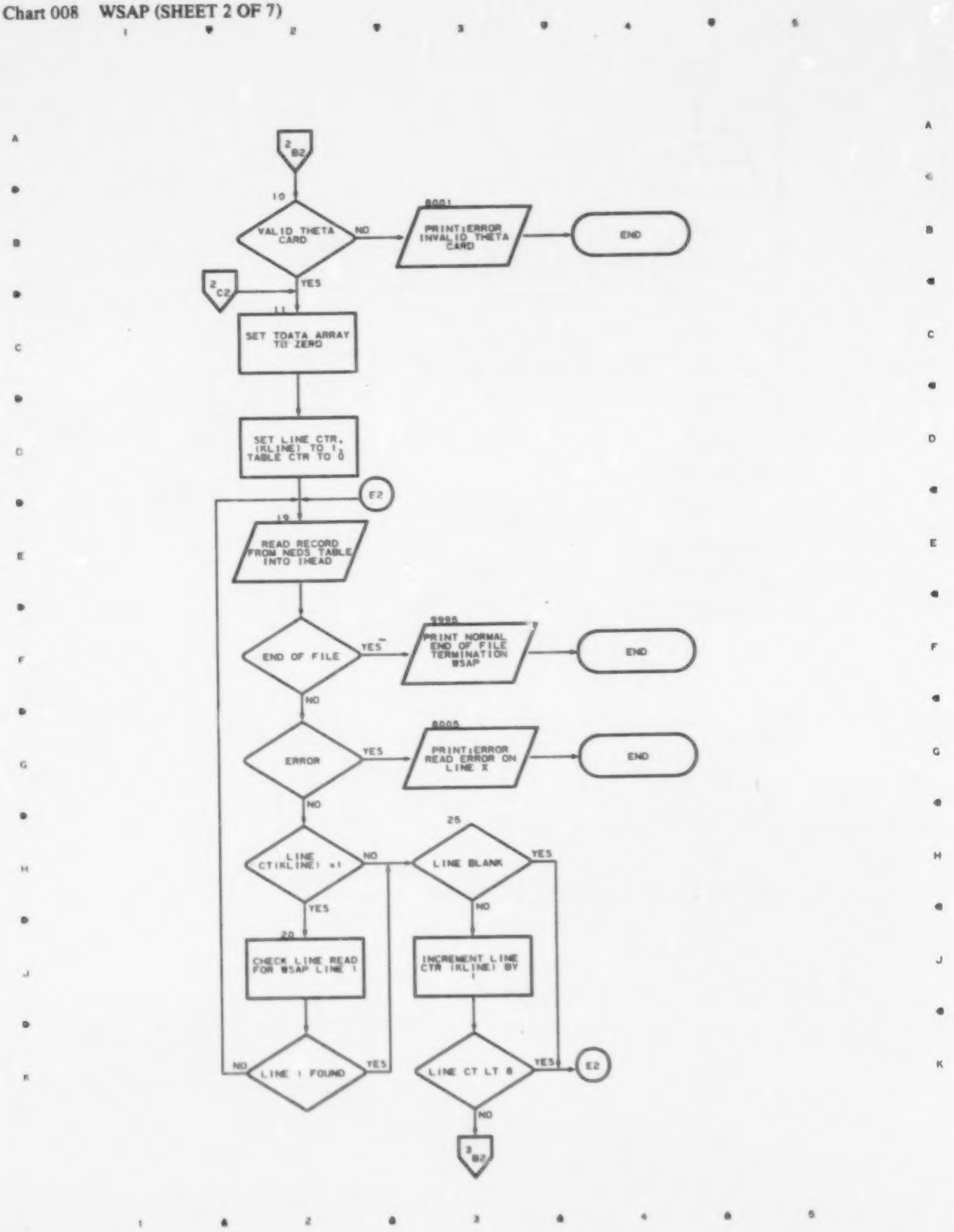

START
BLOCK DATA SEGMENT
INITIALIZE IDRIVR AND ITITL ARRAYS
INITIALIZE PROGRAM VARIABLES
8
FIND TABLE START POINTS IN IDRIVR, STORE IN JTSTBL, FIND NO. TABLES
9
READ THETA CARDS
END OF FILE
YES
8002
PRINT:ERROR NO THETA CARD
END
NO
ERROR
YES
8001
PRINT:ERROR INVALID THETA CARD
END
NO
PRINT THETA CARDS
2 B2
A
B
C
D
E
F
G
H
J
K
1
2
3
4
5

Chart 008 **WSAP (SHEET 2 OF 7)**



2 B2
10
VALID THETA CARD
NO
8001
PRINT:ERROR INVALID THETA CARD
END
YES
2 C2
11
SET TDATA ARRAY TO ZERO
SET LINE CTR. (KLINE) TO 1, TABLE CTR TO 0
E2
19
READ RECORD FROM NEDS TABLE INTO IHEAD
END OF FILE
YES
9999
PRINT NORMAL END OF FILE TERMINATION WSAP
END
NO
ERROR
YES
8005
PRINT:ERROR READ ERROR ON LINE X
END
NO
LINE CT(KLINE) =1
NO
25
LINE BLANK
YES
NO
YES
20
CHECK LINE READ FOR WSAP LINE 1
INCREMENT LINE CTR (KLINE) BY 1
NO
LINE 1 FOUND
YES
LINE CT LT 8
YES
E2
NO
3 B2
1
2
3
4
5
A
B
C
D
E
F
G
H
J
K

Chart 009 WSAP (SHEET 3 OF 7)

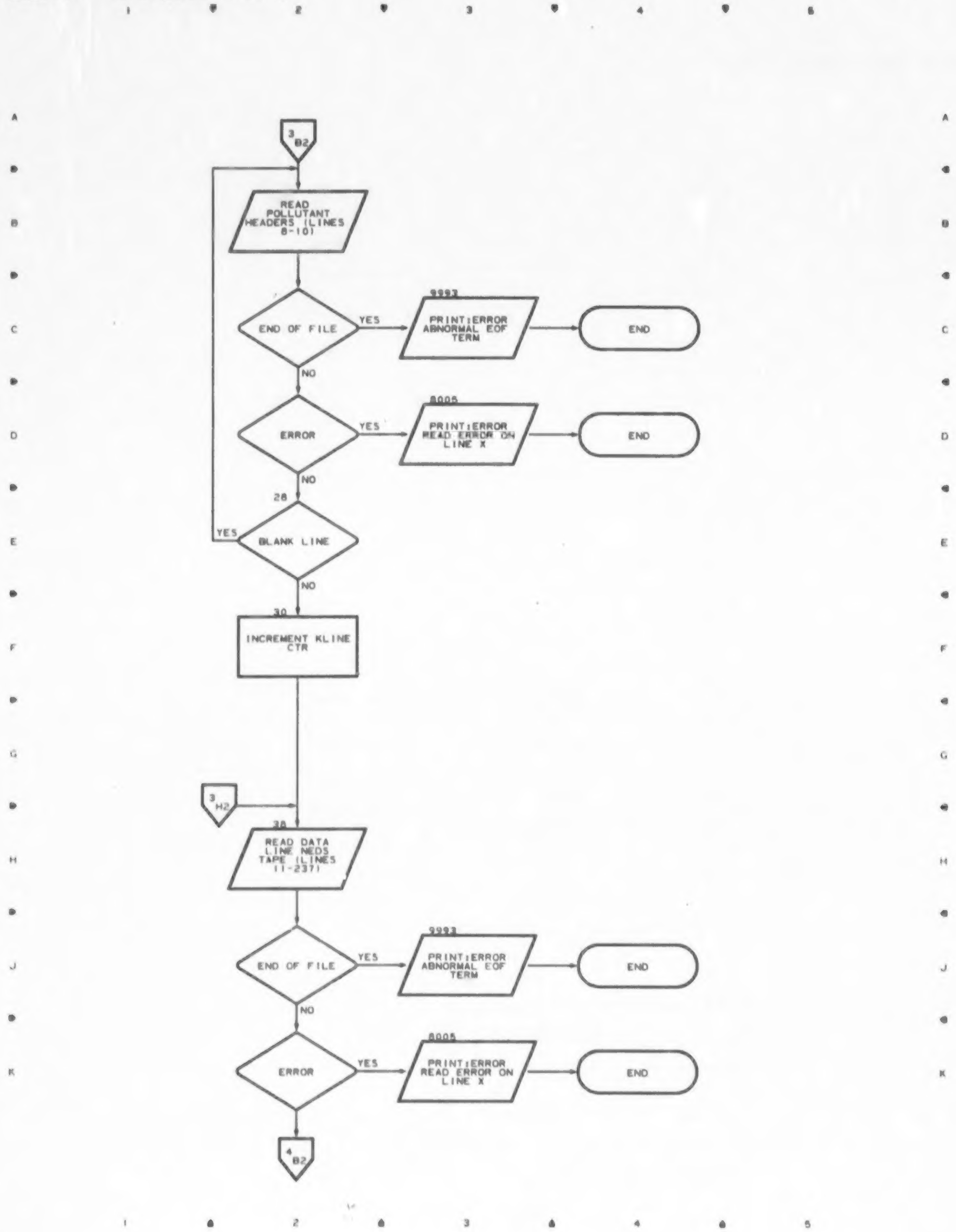

3 B2
READ POLLUTANT HEADERS (LINES 8-10)
END OF FILE
YES
9993
PRINT:ERROR ABNORMAL EOF TERM
END
NO
ERROR
YES
8005
PRINT:ERROR READ ERROR ON LINE X
END
NO
28
BLANK LINE
YES
NO
30
INCREMENT KLINE CTR
3 H2
38
READ DATA LINE NEDS TAPE (LINES 11-237)
END OF FILE
YES
9993
PRINT:ERROR ABNORMAL EOF TERM
END
NO
ERROR
YES
8005
PRINT:ERROR READ ERROR ON LINE X
END
4 B2
1
2
3
4
5
A
B
C
D
E
F
G
H
J
K

Chart 010 WSAP (SHEET 4 OF 7)

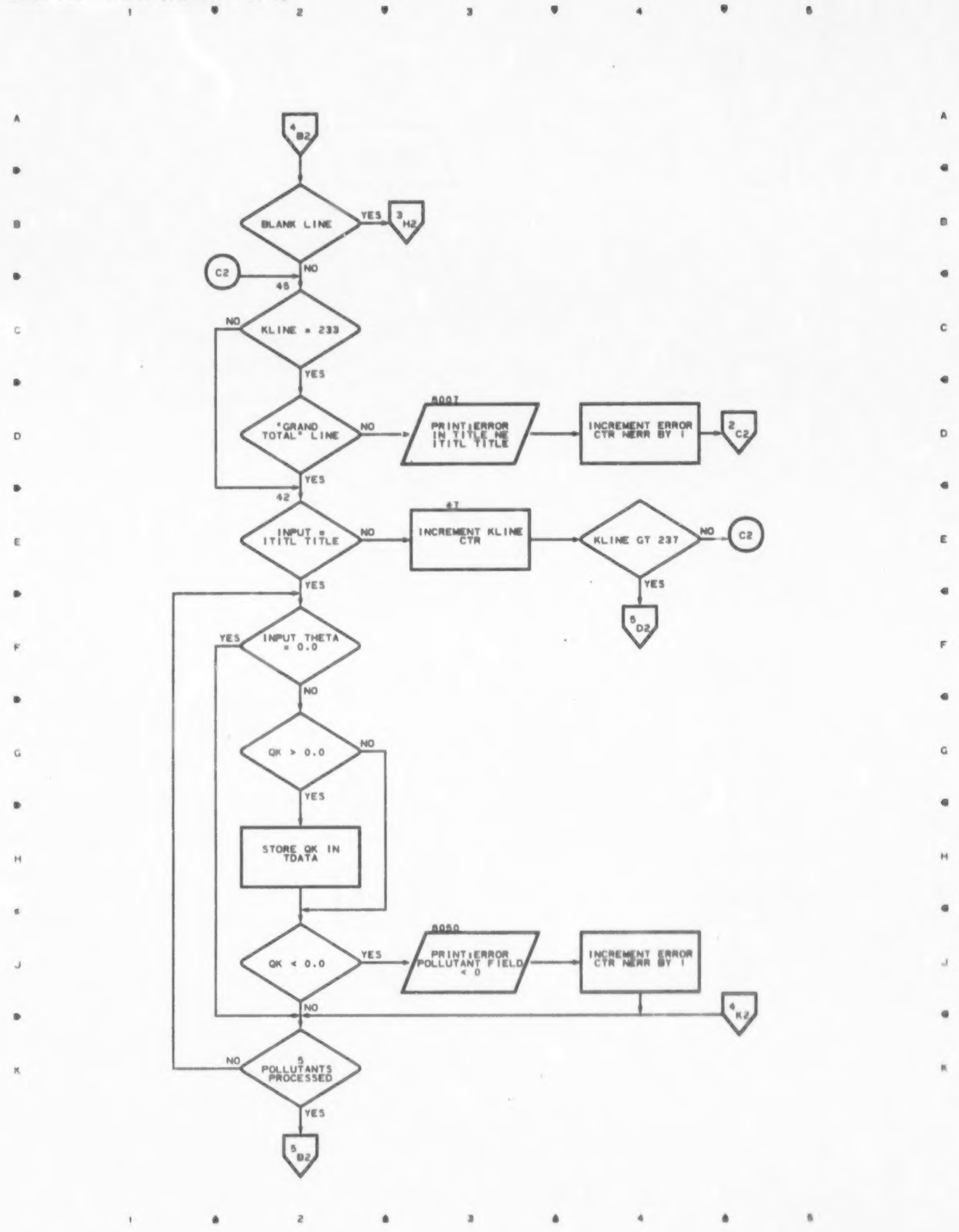

1
2
3
4
5
A
B
C
D
E
F
G
H
J
K
4 B2
BLANK LINE
YES
3 H2
NO
C2
46
KLINE = 233
NO
YES
8007
"GRAND TOTAL" LINE
NO
PRINT:ERROR IN TITLE NE ITITL TITLE
INCREMENT ERROR CTR NERR BY 1
2 C2
YES
42
INPUT = ITITL TITLE
NO
47
INCREMENT KLINE CTR
KLINE GT 237
NO
C2
YES
5 D2
YES
INPUT THETA = 0.0
YES
NO
QK > 0.0
NO
YES
STORE QK IN TDATA
8050
QK < 0.0
YES
PRINT:ERROR POLLUTANT FIELD < 0
INCREMENT ERROR CTR NERR BY 1
NO
4 K2
NO
5 POLLUTANTS PROCESSED
YES
5 B2

Chart 011 WSAP (SHEET 5 OF 7)

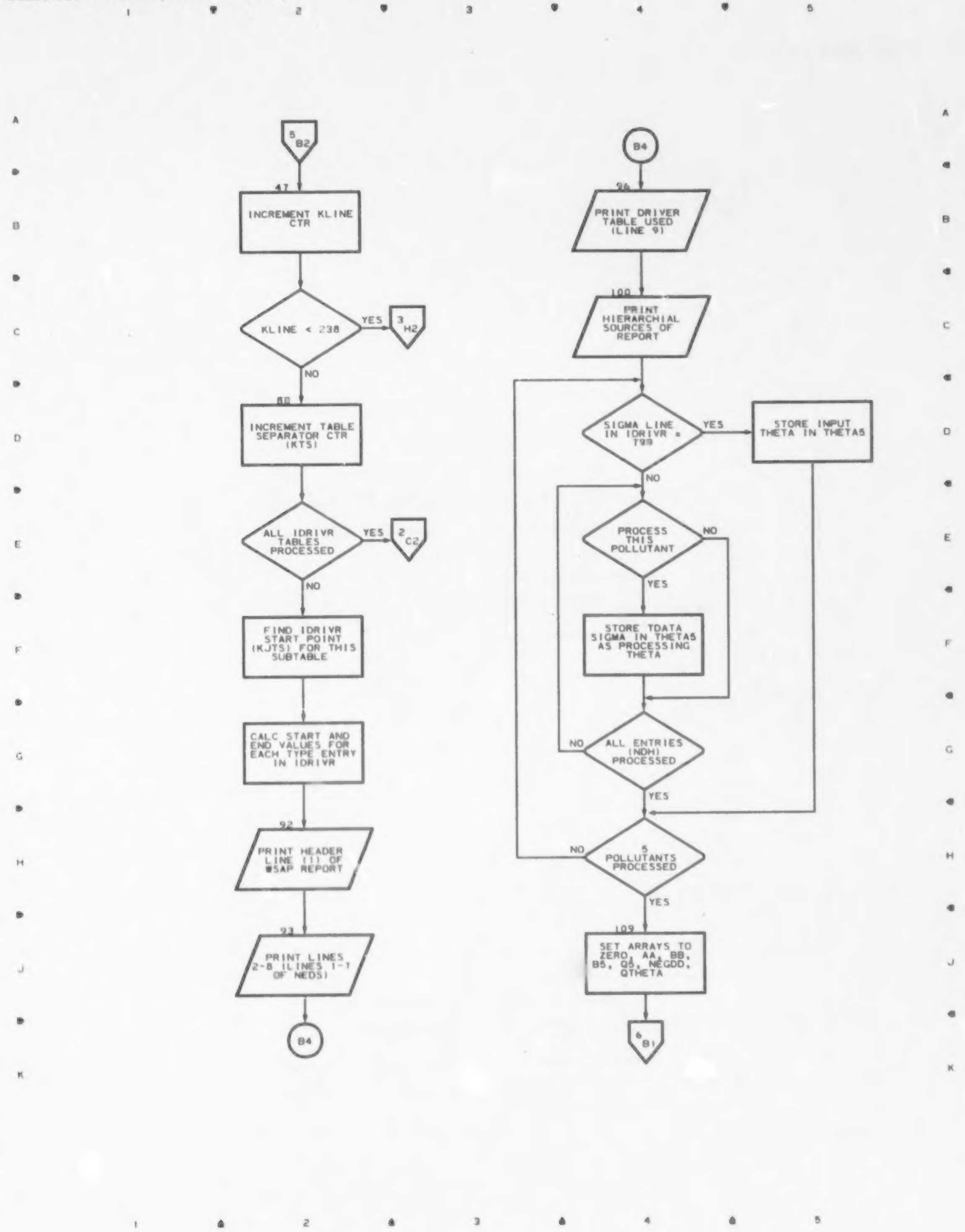

1
2
3
4
5
A
B
C
D
E
F
G
H
J
K
5 B2
47
INCREMENT KLINE CTR
KLINE < 238
YES
3 H2
NO
88
INCREMENT TABLE SEPARATOR CTR (KTS)
ALL IDRIVR TABLES PROCESSED
YES
2 C2
NO
FIND IDRIVR START POINT (KJTS) FOR THIS SUBTABLE
CALC START AND END VALUES FOR EACH TYPE ENTRY IN IDRIVR
92
PRINT HEADER LINE (1) OF WSAP REPORT
93
PRINT LINES 2-8 (LINES 1-7 OF NEDS)
B4
B4
98
PRINT DRIVER TABLE USED (LINE 9)
100
PRINT HIERARCHIAL SOURCES OF REPORT
SIGMA LINE IN IDRIVR = 799
YES
STORE INPUT THETA IN THETA5
NO
PROCESS THIS POLLUTANT
NO
YES
STORE TDATA SIGMA IN THETA5 AS PROCESSING THETA
ALL ENTRIES (NDH) PROCESSED
NO
YES
5 POLLUTANTS PROCESSED
NO
YES
109
SET ARRAYS TO ZERO, AA, BB, B5, Q5, NEGDD, QTHETA
6 B1

Chart 013 WSAP (SHEET 6 OF 7)

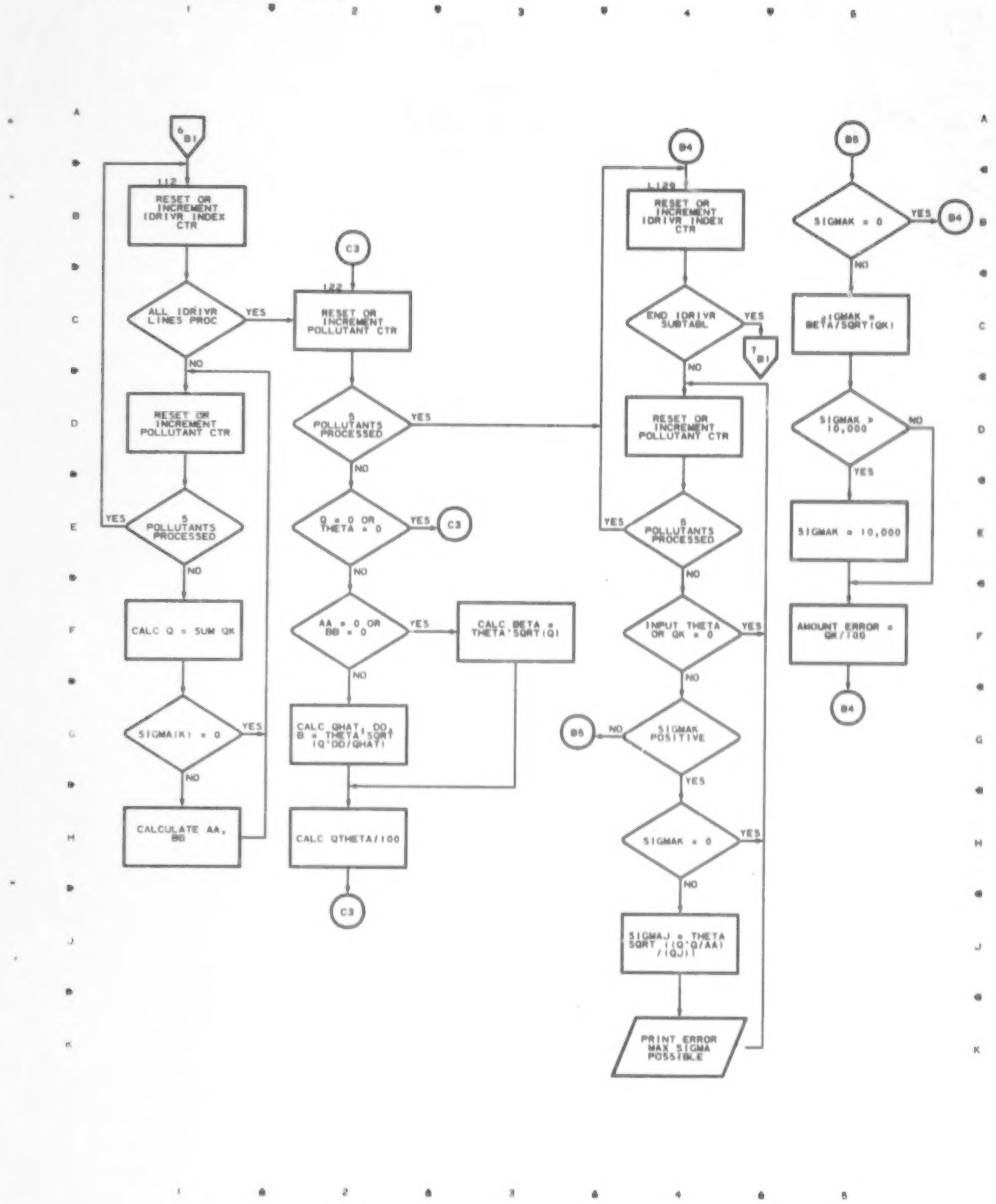
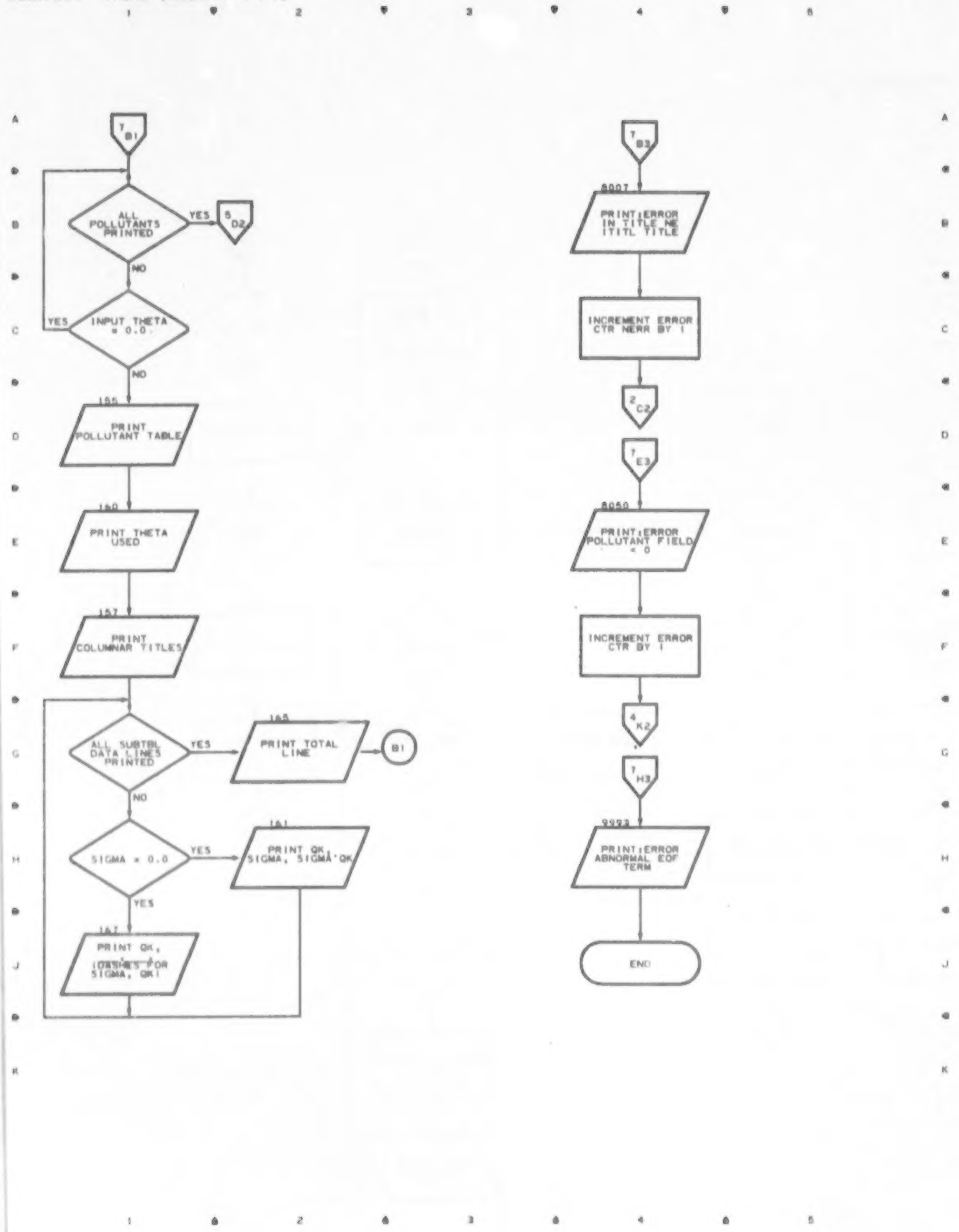

6 B1
112
RESET OR INCREMENT IDRIVR INDEX CTR
ALL IDRIVR LINES PROC
YES
NO
RESET OR INCREMENT POLLUTANT CTR
5 POLLUTANTS PROCESSED
YES
NO
CALC Q = SUM QK
SIGMA(K) = 0
YES
NO
CALCULATE AA, BB
C3
122
RESET OR INCREMENT POLLUTANT CTR
5 POLLUTANTS PROCESSED
YES
NO
Q = 0 OR THETA = 0
YES
C3
NO
AA = 0 OR BB = 0
YES
CALC BETA = THETA'SQRT(Q)
NO
CALC QHAT, DD, B = THETA'SQRT (Q'DD/QHAT)
CALC QTHETA/100
C3
B4
L129
RESET OR INCREMENT IDRIVR INDEX CTR
END IDRIVR SUBTABL
YES
7 B1
NO
RESET OR INCREMENT POLLUTANT CTR
5 POLLUTANTS PROCESSED
YES
NO
INPUT THETA OR QK = 0
YES
NO
SIGMAK POSITIVE
NO
B5
YES
SIGMAK = 0
YES
NO
SIGMAJ = THETA SQRT ((Q'Q/AA) /(QJ))
PRINT ERROR MAX SIGMA POSSIBLE
B5
SIGMAK = 0
YES
B4
NO
SIGMAK = BETA/SQRT(QK)
SIGMAK > 10,000
NO
YES
SIGMAK = 10,000
AMOUNT ERROR = QK/100
B4

Chart 014 WSAP (SHEET 7 OF 7)


1
2
3
4
5
A
B
C
D
E
F
G
H
J
K
7 B1
ALL POLLUTANTS PRINTED
YES
5 D2
NO
INPUT THETA = 0.0.
YES
NO
155
PRINT POLLUTANT TABLE
160
PRINT THETA USED
157
PRINT COLUMNAR TITLES
ALL SUBTBL DATA LINES PRINTED
YES
165
PRINT TOTAL LINE
B1
NO
SIGMA = 0.0
YES
161
PRINT QK, SIGMA, SIGMA*QK
YES
167
PRINT QK, (DASHES FOR SIGMA, QK)
7 B3
8007
PRINT:ERROR IN TITLE NE ITITL TITLE
INCREMENT ERROR CTR NERR BY 1
2 C2
7 E3
8050
PRINT:ERROR POLLUTANT FIELD < 0
INCREMENT ERROR CTR BY 1
4 K2
7 H3
9993
PRINT:ERROR ABNORMAL EOF TERM
END

INPUT-OUTPUT DESCRIPTION

A. Input

1. Card Input

The first and only card is the Theta (θ) card which contains the percent error in the total emission for each pollutant. It has the following format:

Col	Contents	Comment
1-5	THETA	Card identifier
6	blank	
7-12	NNN.NN	θ Pollutant 1
13	blank	
14-19	NNN.NN	θ Pollutant 2
20	blank	
21-26	NNN.NN	θ Pollutant 3
27	blank	
28-33	NNN.NN	θ Pollutant 4
34	blank	
35-40	NNN.NN	θ Pollutant 5

All N's must be an integer (0-9) and the decimal point must be present.

A 0.00 theta will cause that pollutant to be bypassed in processing and printing.

2. National Emissions Data System (NEDS) Print Tape

The description of this NEDS tape can be found in the EPA library as it is generated by another program. Program is presently set up for:

LRECL = 133
BLKSIZE = 2660
RECFM = FBA
LABEL = 1
DENSITY = 1600 BP1

B. Output

The printed report will be in IDRIVR hierarchical table order (table 1 through table 33). Table 4.1 is a sample of the output.

```
                               WEIGHTED SENSITIVITY ANALYSIS REPORT
                                 NATIONAL EMISSIONS DATA SYSTEM
                                 ******************************
                                 ENVIRONMENTAL PROTECTION AGENCY
                                 ******************************
      COUNTY EMISSIONS REPORT                                          RUN DATE: MAY 11, 1973
      ***********************                                 EMISSIONS AS OF: APRIL 15, 1973
         FRANKLIN COUNTY, OHIO

                             SOURCE HIERARCHY                                 DRIVER TABLE   1
                             GRAND TOTAL

                                       PARTICULATES
                THETA =       1.00

DATA                                                           ALLOWABLE ERROR
 NO.      SOURCE CLASSES                   TONS / YR           PERCENT        TONS / YR
 235      AREA SOURCES                      31786.              1.36              433.
 236      POINT SOURCES                     27093.              1.47              399.

                    TOTAL                   58879.              1.00              589.

                                         SOX
                THETA =       1.00

DATA                                                           ALLOWABLE ERROR
 NO.      SOURCE CLASSES                   TONS / YR           PERCENT        TONS / YR
 235      AREA SOURCES                      18368.              1.65              304.
 236      POINT SOURCES                     31853.              1.26              400.

                    TOTAL                   50221.              1.00              502.
```

Table 4.1   SAMPLE WSAP OUTPUT

```
                         WEIGHTED SENSITIVITY ANALYSIS REPORT
                           NATIONAL EMISSIONS DATA SYSTEM
                           ******************************
                          ENVIRONMENTAL PROTECTION AGENCY
                         ********************************              RUN DATE: MAY 11, 1973
                                                                EMISSIONS AS OF: APRIL 19, 1973
  COUNTY EMISSIONS REPORT
  ***********************
     FRANKLIN COUNTY, OHIO                                               DRIVER TABLE   1

                        SOURCE HIERARCHY
                        GRAND TOTAL

                              PARTICULATES

           THETA =      1.00




                                                                 ALLOWABLE ERROR
                                                                              TONS / YR
                                          TONS / YR        PERCENT                433.
   DATA                                                      1.36                 399.
    NO.      SOURCE CLASSES                 31786.           1.47
    235      AREA SOURCES                   27093.                                589.
    236      POINT SOURCES                                   1.00
                                            58879.
                      TOTAL
                                             SOX

                 THETA =       1.00                            ALLOWABLE ERROR
                                                                              TONS / YR
                                                           PERCENT                304.
                                          TONS / YR          1.65                 401.
   DATA                                     18368.           1.26
    NO.      SOURCE CLASSES                 31853.
    235      AREA SOURCES                                                         502.
    236      POINT SOURCES                                   1.00
                                            50221.
                       TOTAL.
```

Table 4.1 (cont.)

TEST DATA

The test input is a National Emissions Data System print tape for 4 states (Illinois, New Jersey, Ohio, Texas). Run date for the tape is April 3, 1973 for emissions as of February 23, 1973. A listing of the tape is furnished with the program listing and the original test tape is delivered with the program.

The following test checks have been made:

1. A 0.00 input Theta cancels processing and printing for that pollutant.
2. An invalid Theta card. THETA missing in columns 1-5.
3. No Theta card present, hopper empty.
4. A no match between input line title and the standard line title in ITITL array.

1. All mathematical calculations have been checked for validity.
2. All IDRIVR tables are correct.
3. The ITITL table agrees with the NEDS test tape.
4. The report is printing correctly, including the printing of dashes for sigma if it equals zero.

OPERATING INSTRUCTIONS

KEYPUNCH INSTRUCTIONS:

Prepare the THETA parameter data and punch the card to the following format:

Col	Contents	Comment
1-5	THETA	
6	blank	
7-12	NNN.NN	θ for Pollutant 1
13	blank	
14-19	NNN.NN	θ for Pollutant 2
20	blank	
21-26	NNN.NN	θ for Pollutant 3
27	blank	
28-33	NNN.NN	θ for Pollutant 4
34	blank	
35-40	NNN.NN	θ for Pollutant 5

All N's must be an integer 0-9 and the decimal point must be present.

A 0.00 theta will cause that pollutant to be bypassed in processing and printing.

INPUT-OUTPUT COORDINATOR INSTRUCTIONS:

Obtain the NEDS report tape for processing.

CONSOLE INSTRUCTIONS:

Mount NEDS tape

Insert THETA card in hopper

Run WSAP program.

SUGGESTIONS, WARNINGS AND CHANGES

SUGGESTIONS:

Improvements to be added:

WSAP has been modified to incorporate the following in WSAP 2:

- Ability to load the ITITL table from cards.
- Capability to load the IDRIVR table from cards.
- Capability to load a known sigma at any category level for any pollutant from cards.

PROGRAM LISTING

The program listed is given under separate cover, together with the users' manual for WSAP. The driver and title tables are given in this section as appendices IV-A and IV-B.

APPENDIX IV-A

DRIVER TABLE (IDRIVR)

The IDRIVR table is a continuous stream of 3 digit integers which controls the selection of data for processing within the WSAP program. It consists of 33 subtables that correspond to the hierarchical levels in the NEDS report.

Each subtable begins with a Table Separator indicator (an integer greater than 799). Following the Table Separator is a series of indicators and line numbers.

Each indicator is an integer which tells the program how many following table entries there are concerning this event. These entries are the actual line numbers in the ITITL table and the TDATA table where the program must go to obtain the data for processing and printing. The ITITL table provides Titles for headings and data lines while the TDATA table provides the amount (QK), sigma and sigma X QK fields.

The number of line number entries in each subtable is variable but the number of indicators and their relative positions within each subtable are fixed.

By calculating the start position of a desired subtable and the start position for each event within the subtable the Driver table can now provide control information (line numbers) to the program.

The following pages provide a more detailed description of the IDRIVR table.

APPENDIX IV-A (continued)

Layout of Driver Table (IDRIVR)

JTS	Table Separator indicator. It is an integer greater than 799 and identifies the beginning of a new table. A 999 entry is used to denote "end of tables".
NH	Count of following (IH) line numbers used for report header information. (1 entry number)
IH	Line numbers used to obtain the heading label information in ITITL. (NH entries)
NDH	Count of following (IDH) line numbers used to obtain θ (or σ) (normally this number is 1)
IDH	Line number where θ or σ data is obtained in TDATA table (NDH entries, usually only 1). If this number is 799 the input θ on card is used.
NL	Count of following (IL) line numbers used for labeling next consecutive lines (1 entry number)
IL	Line numbers where the labeling words are obtained in ITITL table. (NL entries)
ND	Count of following (ID) line numbers used for obtaining the data which is associated with IL (1 entry number)
ID	Line number where the amount data is to be located in TDATA table. (IL entries)

The number of entries for NL and ND should be identical.

APPENDIX IV-A (continued)

Example use of IDRIVR Table stream for 1 sublevel

IDRIVR POSITION	POSITION VARIABLE NAME	IDRIVR DATA	DATA VARIABLE NAME	COMMENT
1	KJTS	801	JTS	Table separator, Begin Table 1
2	KNH	1	NH	There is 1 label item next
3	KIH	233	IH	Use label on line 233 of ITITL
4	KNDH	1	NDH	There is 1 θ line item next
5	KIDH	237	IDH	Use on line 237 of TDATA as θ
6	KNL	2	NL	There are 2 lines of label data next
7	KIL	235	IL	Use label on line 235 of ITITL
8		236		Use label on line 236 of ITITL
9	KND	2	ND	There are 2 lines of amt. data next
10	KID	235	ID	Use the 5 pollutant amts. on line 235 of TDATA
11		236		Use the 5 pollutant amts. on line 236 of TDATA
12	KJTS	802	JTS	Table separator - Begin Table 2
13	KNH	1	NH	

If IDH were 799 the input Theta would be used instead of the sigma on line 237 of the TDATA table.

APPENDIX IV-A (continued)

By using the data in the IDRIVR subtable example on the preceding page the program calculates the following variables.

				Value
KJTS	=	JTSTBL (KTS)	=	1
KNH	=	KJTS + 1	=	2
NH	=	IDRIVR (KNH)	=	1
KIH	=	KNH + 1	=	3
IH	=	IDRIVR (KIH)	=	233
KNDH	=	KIH + NH	=	4
NDH	=	IDRIVR (KNDH)	=	1
KIDH	=	KNDH + 1	=	5
IDH	=	IDRIVR (KIDH)	=	237
KNL	=	KIDH + NDH	=	6
NL	=	IDRIVR (KNL)	=	2
KIL	=	KNL + 1	=	7
IL	=	IDRIVR (KIL)	=	235
KND	=	KIL + NL	=	9
ND	=	IDRIVR (KND)	=	2
KID	=	KND + 1	=	10
ID	=	IDRIVR (KID)	=	235

Once the above variables are calculated for any given IDRIVR subtable (1-33) the processing of data for that table can begin.

```
  801    1  233    1  799    2  235  236    2  235  236  802    1  236    1  236    4   11  130  146
  231    4  129  145  192  231  803    1  235    1  235    4   11  146  191  217    4  128  189  216
  230  804    2   11  129    1  129    2   13  103    2  102  126    0    0  805    1  130    1  145
   13  132  133  134  135  136  137  138  139  140  141  142  143  144   13  132  133  134  135  136
  137  138  139  140  141  142  143  144  806    2  146  190    1  190    4  148  157  171  187    4
  152  170  186  187  807    2   11  128    1  128    1  191    1  191  808    2  146  189    1  189
    3  153  157  171    3  156  160  185  809    1  191    1  216    6  193  194  199  204  209  215
    6  193  198  203  208  214  215  810    1  217    1  230   11  219  220  221  222  223  224  225
  226  227  228  229   11  219  220  221  222  223  224  225  226  227  228  229  811    2   13  102
    1  102    4   22   35   71   99    4   34   70   98   99  812    1  103    1  126    5  104  110
  117  121  125    5  109  116  120  124  125  813    2  146  148    1  152    3  149  150  151    3
  149  150  151  814    3  146  157  170    1  170    4  158  161  164  166    4  160  163  165  167
  815    2  146  171  186    1  186    5  172  175  178  180  182    5  174  177  179  181  183    0
  816    2   13  101    1  101    3   14   35   71    3   21   65   97    0    0    0    0    0    0
  817    2  146  153    1  156    2  154  155    2  154  155    0    0    0    0    0    0    0    0
  818    3  146  157  169    1  169    2  158  161    2  159  162    0    0    0    0    0    0    0
  819    3  146  171  185    1  185    2  172  175    2  173  176    0    0    0    0    0    0    0
  820    3  191  193  194    1  198    3  195  196  197    3  195  196  197    0    0    0    0    0
  821    3  191  193  199    1  203    3  200  201  202    3  200  201  202    0    0    0    0    0
  822    2  191  204    1  209    3  205  206  207    3  205  206  207    0    0    0    0    0    0
  823    2  191  205    1  214    4  210  211  212  213    4  210  211  212  213    0    0    0    0
  824    3   11   13   22    1   34   11   23   24   25   26   27   28   29   30   31   32   33   11
   23   24   25   26   27   28   29   30   31   32   33    0    0    0    0    0    0    0    0    0
  825    4   11   13   35   70    1   70   12   36   39   42   44   47   50   53   56   59   62   64
   66   12   38   41   43   46   49   52   55   58   61   63   65   67    0    0    0    0    0    0
  826    4   11   13   71   98    1   98    0   72   75   78   80   83   86   89   92   94    9   74
   77   79   82   85   88   91   93   95    0    0  827    3   11  103  104    1  109    4  105  106
  107  108    4  105  106  107  108    0    0    0  828    3   11  103  110    1  116    5  111  112
  113  114  115    5  111  112  113  114  115    0  829    3   11  103  117    1  120    2  118  119
    2  118  119    0    0    0    0    0    0    0  830    3   11  103  121    1  124    2  122  123
    2  122  123    0    0    0    0    0    0    0  831    3   11   13   14    1   21    6   15   16
   17   18   19   20    6   15   16   17   18   19   20    0    0    0    0    0    0    0    0    0
  832    4   11   13   35   69    1   69    8   36   39   44   47   50   53   56   59    8   37   40
   45   48   51   54   57   60    0    0    0    0  833    4   11   13   71   97    1   97    6   72
   75   80   83   86   89    6   73   76   81   84   87   90    0    0    0    0    0    0    0  999
```

DRIVER TABLE
(IDRIVR)

APPENDIX IV-B

LABEL TABLE

LINE NO. **LABEL**

```
 1
 2
 3
 4
 5
 6
 7
 8
 9
10
11  FUEL COMBUSTION
12  ***************
13       EXTERNAL COMBUSTION
14            RESIDENTIAL FUEL (AREA)
15                 ANTHRACITE COAL
16                 BITUMINOUS COAL
17                 DISTILLATE OIL
18                 RESIDUAL OIL
19                 NATURAL GAS
20                 WOOD
21                 TOTAL (RESIDENTIAL)
22            ELEC GENERATION (POINT)
23                 ANTHRACITE COAL
24                 BITUMINOUS COAL
25                 LIGNITE
26                 RESIDUAL OIL
27                 DISTILLATE OIL
28                 NATURAL GAS
29                 PROCESS GAS
30                 COKE
31                 BAGASSE
32                 SOLID WASTE/COAL
33                 OTHER
34                 TOTAL (ELEC GEN)
35            INDUSTRIAL FUEL
36                 ANTHRACITE COAL
37                      AREA SOURCES
38                      POINT SOURCES
39                 BITUMINOUS COAL
40                      AREA SOURCES
41                      POINT SOURCES
42                 LIGNITE
43                      POINT SOURCES
44                 RESIDUAL OIL
```

LABEL TABLE (cont.)

```
45                  AREA SOURCES
46                  POINT SOURCES
47             DISTILLATE OIL
48                  AREA SOURCES
49                  POINT SOURCES
50             NATURAL GAS
51                  AREA SOURCES
52                  POINT SOURCES
53             PROCESS GAS
54                  AREA SOURCES
55                  POINT SOURCES
56             COKE
57                  AREA SOURCES
58                  POINT SOURCES
59             WOOD
60                  AREA SOURCES
61                  POINT SOURCES
62             LIQUID PETROL GAS
63                  POINT SOURCES
64             BAGASSE
65                  POINT SOURCES
66             OTHER
67                  POINT SOURCES
68             TOTAL (INDUSTRIAL)
69                  AREA SOURCES
70                  POINT SOURCES
71        COMM-INSTITUTIONAL FUEL
72             ANTHRACITE COAL
73                  AREA SOURCES
74                  POINT SOURCES
75             BITUMINOUS COAL
76                  AREA SOURCES
77                  POINT SOURCES
78             LIGNITE
79                  POINT SOURCES
80             RESIDUAL OIL
81                  AREA SOURCES
82                  POINT SOURCES
83             DISTILLATE OIL
84                  AREA SOURCES
85                  POINT SOURCES
86             NATURAL GAS
87                  AREA SOURCES
88                  POINT SOURCES
89             WOOD
90                  AREA SOURCES
91                  POINT SOURCES
92             LIQUID PETROL GAS
93                  POINT SOURCES
94             OTHER
95                  POINT SOURCES
```

LABEL TABLE (cont.)

```
  96                TOTAL (COMM-INST)
  97                    AREA SOURCES
  98                    POINT SOURCES
  99            OTHER (POINT)
 100            TOTAL (EXTERNAL COMB)
 101                AREA SOURCES
 102                POINT SOURCES
 103        INTERNAL COMBUSTION (POINT)
 104            ELECTRIC GENERATION
 105                DISTILLATE OIL
 106                NATURAL GAS
 107                DIESEL
 108                OTHER
 109                TOTAL (ELEC GEN)
 110            INDUSTRIAL FUEL
 111                DISTILLATE OIL
 112                NATURAL GAS
 113                GASOLINE
 114                DIESEL FUEL
 115                OTHER
 116                TOTAL (INDUSTRIAL)
 117            COMM-INSTITUTIONAL
 118                DIESEL
 119                OTHER
 120                TOTAL (COMM-INST)
 121            ENGINE-TESTING
 122                AIRCRAFT
 123                OTHER
 124                TOTAL (ENG TESTNG)
 125            OTHER (POINT)
 126            TOTAL (INTERNAL COMB)
 127        TOTAL (FUEL COMBUSTION)
 128            AREA SOURCES
 129            POINT SOURCES
 130    INDUSTRIAL PROCESS (POINT)
 131    **************************
 132        CHEMICAL MANUFACTURING
 133        FOOD/AGRICULTURAL
 134        PRIMARY METAL
 135        SECONDARY METALS
 136        MINERAL PRODUCTS
 137        PETROLEUM INDUSTRY
 138        WOOD PRODUCTS
 139        EVAPORATION
 140        METAL FABRICATION
 141        LEATHER PRODUCTS
 142        TEXTILE MANUFACTURING
 143        INPROCESS FUEL
 144        OTHER/NOT CLASSIFIED
 145        TOTAL (INDUSTRIAL)
 146    SOLID WASTE DISPOSAL
 147    ********************
```

LABEL TABLE (cont.)

```
148         GOVERNMENT (POINT)
149             MUNICIPAL INCINERATION
150             OPEN BURNING
151             OTHER
152             TOTAL (GOVERNMENT)
153         RESIDENTIAL (AREA)
154             ON SITE INCINERATION
155             OPEN BURNING
156             TOTAL (RESIDENTIAL)
157         COMMERCIAL-INSTITUTIONAL
158             ON SITE INCINERATION
159                 AREA SOURCES
160                 POINT SOURCES
161             OPEN BURNING
162                 AREA SOURCES
163                 POINT SOURCES
164             APARTMENT
165                 POINT SOURCES
166             OTHER
167                 POINT SOURCES
168             TOTAL (COMM-INST)
169                 AREA SOURCES
170                 POINT SOURCES
171         INDUSTRIAL
172             ON SITE INCINERATION
173                 AREA SOURCES
174                 POINT SOURCES
175             OPEN BURNING
176                 AREA SOURCES
177                 POINT SOURCES
178             AUTO BODY INCINERATION
179                 POINT SOURCES
180             RAIL CAR BURNING
181                 POINT SOURCES
182             OTHER
183                 POINT SOURCES
184             TOTAL (INDUSTRIAL)
185                 AREA SOURCES
186                 POINT SOURCES
187         OTHER (POINT)
188         TOTAL (SOLID WASTE DISP)
189             AREA SOURCES
190             POINT SOURCES
191     TRANSPORTATION (AREA)
192     *********************
193         LAND VEHICLES
194             GASOLINE
195                 LIGHT VEHICLES
196                 HEAVY VEHICLES
197                 OFF HIGHWAY
198                 TOTAL (GASOLINE)
199             DIESEL
```

LABEL TABLE (cont.)

```
200              HEAVY VEHICLES
201              OFF HIGHWAY
202              RAIL
203              TOTAL (DEISEL)
204      AIRCRAFT
205          MILITARY
206          CIVIL
207          COMMERCIAL
208          TOTAL (AIRCRAFT)
209      VESSELS
210          BITUMINOUS COAL
211          DIESEL FUEL
212          RESIDUAL OIL
213          GASOLINE
214          TOTAL (VESSELS)
215      GAS HANDLING EVAP LOSS
216      TOTAL (TRANSPORTATION)
217  MISCELLANEOUS (AREA)
218  **********************
219      FOREST FIRE/AGRIC BURNING
220      STRUCTURAL FIRES
221      COAL REFUSE BURNING
222      SLASH BURNING
223      FROST CONTROL
224      SOLVENT EVAPORATION LOSS
225      DUST SOURCES
226          DIRT ROADS
227          DIRT AIRSTRIPS
228          CONSTRUCTION
229          ROCK HANDLING/STORING
230      TOTAL (MISCELLANEOUS)
231  OTHER (POINT)
232  ***************
233  GRAND TOTAL
234  *************
235      AREA SOURCES
236      POINT SOURCES
237      TOTAL
238
```

Section V

CONCLUSIONS

A weighted sensitivity analysis methodology has been developed in this contract to establish the statistical quality of emission inventories. A summary of the results, including developments beyond the original scope of work, is given in Section I of this final report. Section II presents a detailed explanation of the methodology, and the complete theoretical development is documented in Appendix A. Section III and Appendix B provide numerical analyses to illustrate the application of the technique and demonstrate the adequacy of the software. The latter is fully documented in Section IV, which is structured in consonance with EPA's outline for software documentation. The program listing and user's manual is to be delivered under separate cover.

The utility of the methodology that has been developed is manyfold. It is consistent with activity forecasting requirements and serves to establish percentage error requirements for source categories so as to satisfy given error bounds for the overall emissions inventory at a given level of statistical confidence. It provides results useful for planning air pollution control enforcement activity. For example, suppose that for a given source class k,

$$\frac{\sigma_K Q_K}{100} = q_K$$

is the allowed error quantity (in physical units) that satisfies σ_k, and suppose that field measurements indicate that the actual error quantity is some value $\vec{q}_K > q_K$; then, the fraction

$$\frac{\vec{q}_K - q_K}{\vec{q}_K}$$

immediately gives the percentage reduction in error quantity which is necessary to comple with σ_k, and appropriate corrective action can be planned accordingly.

The versatility and wide range of applicability of the technique is further illustrated in Appendix C to this final report, which shows an application of the technique to assist the Commonwealth of Virginia's State Air Pollution Control Board in achieving an approvable implementation plan for attaining secondary standards for particulate matter by 1975.

The formulation of the weighted sensitivity analysis presented in this report possesses a high degree of generality. It can be applied to compute component error requirements for inventories of emissions (or any other kind of) data which exhibit a hierarchial (tree-like) structure, as exemplified by NEDS reports. A concrete case of interest could arise by multiplying the hierarchial table of emissions data (i.e., the table of Q_k's) by some set of "effect" factors such as the health effect factors provided by Walther [Reference 4]. Denoting the effect factor by f_k and the resulting effect as E_k, $E_k = f_k Q_k$ for each source in a given category, with $E = \sum_{k=1}^{N} f_k Q_K$ k giving the total effect for that category. In this case, the ratios E_k/E provide weightings analogous to Qk/Q in the standard application of the technique, i.e., it can be readily extended to perform weighted sensitivity analysis on the contributions of the major air pollutants and their sources by effect as well as by weight or mass. Additional prospective extensions of the analysis are its application to emission factors and to emissions data at the SCC level of aggregation.

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Appendix A

THEORETICAL ANALYSIS

This appendix documents the theoretical development of the basic weighted sensitivity analysis technique for emissions data and its various extensions. These analytical developments are based on well-known theory [References 1, 2, 5] and well-established assumptions. Section II of this final report provides a descriptive discussion of the assumptions adopted, their statistical interpretation, and their practical implications. Concise mathematical notation will be used for the theoretical analysis in this appendix.

A.1 Weighted Sensitivity Analysis

The objective of sensitivity analysis is to determine the effect (changes) on some measure of performance due to changes in each component that makes up the measure of performance. In the simplest case the measure of performance is the sum of component measures. Let T be the total measure of performance and C_K be the K^{th} component. Then,

$$T = \sum_{K=1}^{N} C_K$$

and any change in T (ΔT) due to changes in each of the components (ΔC_K) would be related to these component changes as

$$\Delta T = \sum_{K=1}^{N} \Delta C_K \tag{A-2}$$

However, each component may be dependent on one or more primitive parameters so that, for example,

$$C_K = C_K (X) \tag{A-3}$$

and

$$\Delta C = \frac{\partial C}{\partial x} \Delta x \tag{A-4}$$

if X is a column vector, then with the gradient operator defined as

$$\nabla^T \equiv \left(\frac{\partial}{\partial x_1}, \frac{\partial}{\partial x_2}, \ldots, \frac{\partial}{\partial x_m} \right) \tag{A-5}$$

the propagating change formulation takes on the form

$$\Delta C_K = \left(\nabla^T C_K \right) \Delta x \tag{A-6}$$

For this exposition we shall use the single variable notation with the understanding that, should multivariable parameters be considered, then the partial derivatives must be thought of as gradients. The relationship of changes indicated in Equation A-2 is valid for deterministic changes. However, if the changes are uncertain or stochastic, the changes must be indicated by a statistical measure of dispersion (e.g., variance, standard deviation) rather than by differentials. Thus,

$$V(T) = \sum_{K=1}^{N} V(C_K) \qquad \text{(A-7)}$$

where v(•) is the statistical variance (the square of the standard deviation) and the component variances are assumed to be uncorrelated with each other. Let

$$V(T) = T^2\theta^2 \quad \text{where } 0 \leq \theta \leq 1 \qquad \text{(A-8)}$$

and 100 θ is the percent error or deviation of T. Similarly, let

$$V(C_K) = C_K^2 \gamma_K^2 \quad \text{where } 0 \leq \gamma_K \leq 1 \qquad \text{(A-9)}$$

and 100 γ_K is the percent error or deviation of C_K. Then Equation A-7 becomes

$$T^2\theta^2 = \sum_{K=1}^{N} C_K^2 \gamma_K^2 \qquad \text{(A-10)}$$

or

$$\theta = \sqrt{\sum_{K=1}^{N} \left(\frac{C_K}{T}\right)^2 \gamma_K^2} \qquad \text{(A-11)}$$

where 100 C_K/T is the percent of C_K in T. Equation A-11 relates the error in T to the errors in each of the components, with all errors represented as fractions (or percentages); moreover, these component errors are weighted according to the contribution of each component measure to the total measure of performance.

Because of this weighting it becomes possible to assess the significance of each component as it relates to the confidence (or error) of the total measure of performance.

The following subsections exhibit the application of this method of analysis to emissions data as well as some numerical examples.

A.2 Application to Emissions Data

This analysis is based upon Equation A-10. Let C_K be replaced by Q_K, where Q_K designates the emissions (e.g., in tons/year) of a specific air pollutant produced by source class K. Also, let σ_K be the error (replacing γ_K) in Q_K. Similarly, let Q replace T for total emissions with error θ. Then in analogy with Equation A-10 we have

$$Q^2 \theta^2 = \sum_{K=1}^{N} Q_K^2 \sigma_K^2 \qquad \text{(A-12)}$$

where

$$Q = \sum_{K=1}^{N} Q_K \qquad \text{(A-13)}$$

By division we obtain

$$1 = \sum_{K=1}^{N} \left(\frac{Q_K}{Q} \right)^2 \left(\frac{\sigma_K}{\theta} \right)^2 \qquad \text{(A-14)}$$

The objective of this analysis is to obtain σ_K for each class K according to some value of θ (error in total). As a first approximation we can assume that each term in Equation A-14 contributes the same amount to the total. Thus,

$$1/N = (Q_K/Q)^2 \; (\sigma_K/\theta)^2 \qquad \text{(A-15)}$$

whence,

$$\sigma_K = \theta / [\sqrt{N} \; (Q_K/Q)] \qquad \text{(A-16)}$$

where N is the number of source classes.

We can interpret Equation A-16 as indicating the present error allowable (σ_K) in forecasting emissions from source class K given the percent error allowable (θ) in forecasting total emissions. σ_K can be modified either by changing θ or by regrouping the source classes, which changes N and Q_K simultaneously.

As a second approximation, the analysis can be modified to allow each source class k to contribute to the total error an amount proportional to its relative physical contribution to the total pollutant emission Q, as given by the ratio Q_k/Q. Analytically, it is only necessary to note that

$$\sum_{K=1}^{N} Q_K/Q = 1$$

i.e., the summation of all the weightings Q_k/Q must necessarily add up to one. Since, from Equation A-14,

$$1 = \sum_{K=1}^{N}\left(\frac{Q_K}{Q}\right)^2\left(\frac{\sigma_K}{\theta}\right)^2$$

it follows that:

$$\sum_{K=1}^{N}\frac{Q_K}{Q} = \sum_{K=1}^{N}\left(\frac{Q_K}{Q}\right)^2\left(\frac{\sigma_K}{\theta}\right)^2 \qquad \text{(A-17)}$$

or, in expanded form:

$$\frac{Q_1}{Q} + \frac{Q_2}{Q} + \cdots \frac{Q_N}{Q} = \left(\frac{Q_1}{Q}\right)^2\left(\frac{\sigma_1}{\theta}\right)^2 + \left(\frac{Q_2}{Q}\right)^2\left(\frac{\sigma_2}{\theta}\right)^2 + \cdots + \left(\frac{Q_N}{Q}\right)^2\left(\frac{\sigma_N}{\theta}\right)^2$$

Arbitrarily, equating both sides of the equation term by term yields

$$\begin{aligned} Q_1/Q &= (Q_1/Q)^2(\sigma_1/\theta)^2 \\ Q_2/Q &= (Q_2/Q)^2(\sigma_2/\theta)^2 \\ &\vdots \\ Q_N/Q &= (Q_N/Q)^2(\sigma_N/\theta)^2 \end{aligned}$$

or, more concisely:

$$Q_k/Q = (Q_k/Q)^2 \, (\sigma_k/\theta)^2 \qquad \text{(A-18)}$$

for each source class k. This revised formulation assumes that each term contributes to the total an amount proportional to Q_k/Q. Then, from equation A-18

$$1 = (Q_k/Q)(\sigma_k/\theta)^2$$

and we obtain

$$\sigma_k = \theta\sqrt{Q/Q_k} \qquad \text{(A-19)}$$

as the formula to compute σ_k for each source class k. This formulation satisfies the same practical requirements as the original one and, in addition, provides a better working assumption from the viewpoint of interpretation of the results for enforcement purposes. Equation (A-19) is the basic formula of the weighted sensitivity analysis techique. As with equation (A-16), we can interpret Equation A-19 as indicating the percent error allowable (σ_K) in forecasting emissions from source class K given the percent error allowable (θ) in forecasting total emissions. σ_K can be modified either by changing θ or by regrouping the source classes, which changes Q/Q_K.

A.3 Extension to account for fixed errors

Refer back to equation (A-14) and consider the equations

$$1 = \sum_{K \neq J}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{Q}\right)^2 + \left(\frac{Q_J}{Q}\right)^2 \left(\frac{\sigma_J}{Q}\right)^2 \qquad \text{(A-20)}$$

$$1 = \sum_{K \neq J} \frac{Q_K}{Q} \qquad \text{(A-21)}$$

if Q_J is known apriori, then

$$\frac{Q_J}{Q} + D = \left(\frac{Q_J}{Q}\right)^2 \left(\frac{\sigma_J}{Q}\right)^2 \qquad \text{(A-22)}$$

where

$$D = \left(\frac{Q_J}{Q}\right)^2 \left(\frac{\sigma_J}{Q}\right)^2 - \frac{Q_J}{Q} \qquad \text{(A-23)}$$

Equating (A-20) and (A-21) then subtracting (A-22) yields

$$\sum^{N} \frac{Q_K}{Q} \; [illegible] \; \sum^{N} [illegible]$$

with reference to (A-21) we note

$$1 - \frac{Q_J}{Q} = \sum_{K \neq J}^{N} \frac{Q_K}{Q} \qquad \text{(A-25)}$$

whence

$$1 = \frac{Q}{Q - Q_j} \sum_{K \neq j}^{N} \frac{Q_K}{Q} \qquad \text{(A-26)}$$

so that

$$D = \frac{DQ}{Q - Q_j} \sum_{K \neq j}^{N} \frac{Q_K}{Q} \qquad \text{(A-27)}$$

Substituting (A-27) into (A-24) yields

$$\sum_{K \neq j}^{N} \frac{Q_K}{Q} - \frac{DQ}{Q - Q_j} \sum_{K \neq j}^{N} \frac{Q_K}{Q} = \sum_{K \neq j}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\theta}\right)^2 \qquad \text{(A-28)}$$

or

$$\left[\frac{Q(1-D) - Q_j}{Q - Q_j}\right] \sum_{K \neq j}^{N} \frac{Q_K}{Q} = \sum_{K \neq j}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\theta}\right)^2 \qquad \text{(A-29)}$$

with the assumption that

$$\left[\frac{Q(1-D) - Q_j}{Q - Q_j}\right] \frac{Q_K}{Q} \overset{\downarrow}{=} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\theta}\right)^2 \qquad \text{(A-30)}$$

for k≠j

we get

$$\sigma_K^{\,2} = \left[\frac{Q(1-D) - Q_j}{Q - Q_j}\right]\frac{\sigma^2 Q}{Q_K} \qquad \text{(A-31)}$$

or

$$\sigma_K = \sigma\sqrt{\frac{Q}{Q_K}\left[\frac{Q(1-D) - Q_j}{Q - Q_j}\right]} = \sigma\sqrt{\frac{Q}{Q_K}\left[\text{[illegible]}\right]} \qquad \text{(A-32)}$$

If σ_K is unknown for K = 1, 2, ---, m, but σ_j is known for j = m + 1, ---, N then (A-20) becomes

$$1 = \sum_{K=1}^{m}\left(\frac{Q_K}{Q}\right)^2\left(\frac{\sigma_K}{\sigma}\right)^2 + \sum_{j=m+1}^{N}\left(\frac{Q_j}{Q}\right)^2\left(\frac{\sigma_j}{\sigma}\right)^2 \qquad \text{(A-33)}$$

and (A-21) becomes

$$1 = \sum_{K=1}^{m}\frac{Q_K}{Q} + \sum_{j=m+1}^{N}\frac{Q_j}{Q} \qquad \text{(A-34)}$$

We define D_j to satisfy

$$\frac{Q_j}{Q} + D_j = \left(\frac{Q_j}{Q}\right)^2\left(\frac{\sigma_j}{\sigma}\right)^2 \qquad \text{(A-35)}$$

where

$$D_j = \left(\frac{Q_j}{Q}\right)^2\left(\frac{\sigma_j}{\theta}\right)^2 - \frac{Q_j}{Q} \qquad \text{(A-36)}$$

Equating (A-33) and (A-34) then subtracting (A-35) for j = m + 1, ---, N yields

$$\sum_{K=1}^{m} \frac{Q_K}{Q} - \sum_{j=m+1}^{N} D_j = \sum_{K=1}^{m}\left(\frac{Q_K}{Q}\right)^2\left(\frac{\sigma_K}{\theta}\right)^2 \qquad \text{(A-37)}$$

Let

$$D \equiv \sum_{j=m+1}^{N} D_j \qquad \text{(A-38)}$$

and

$$\tilde{Q} \equiv \sum_{j=m+1}^{N} \frac{Q_j}{Q} \qquad \text{(A-39)}$$

with reference to (A-34)

$$1 - \tilde{Q} = \sum_{K=1}^{m} \frac{Q_K}{Q} \qquad \text{(A-40)}$$

whence

$$1 = \frac{1}{1-\tilde{Q}} \sum_{K=1}^{m} \frac{Q_K}{Q} \qquad \text{(A-41)}$$

so that

$$D = \frac{D}{1-\tilde{Q}} \sum_{K=1}^{m} \frac{Q_K}{Q} \qquad \text{(A-42)}$$

Substitution of (A-38) and (A-39) into (A-37) yields

$$\sum_{K=1}^{m} \frac{Q_K}{Q} - \frac{D}{1-\tilde{Q}} \sum_{K=1}^{m} \frac{Q_K}{Q} = \sum_{K=1}^{m} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \qquad \text{(A-43)}$$

or

$$\left(\frac{1 - D - \tilde{Q}}{1-\tilde{Q}}\right) \sum_{K=1}^{m} \frac{Q_K}{Q} = \sum_{K=1}^{m} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \qquad \text{(A-44)}$$

with the assumption that

$$\left(\frac{1 - D - \widetilde{Q}}{1-\tilde{Q}}\right) \frac{Q_K}{Q} \overset{\downarrow}{=} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \qquad \text{(A-45)}$$

we get

$$\sigma_K^2 = \theta^2 \frac{Q}{Q_K}\left(\frac{1-D-\tilde{Q}}{1-\tilde{Q}}\right) \qquad \text{(A-46)}$$

or

$$\sigma_K = \theta\sqrt{\frac{Q}{Q_K}\left(\frac{1-D-\tilde{Q}}{1-\tilde{Q}}\right)} \qquad \text{(A-47)}$$

Equation (A-47) constitutes a generalization of equation (A-19) to cover the case where one or more of the errors associated with the subclasses of a given source class are to be fixed by the analyst. Even assuming zero error for the other components, however, there is of course a maximum value that can be attached to the fixed errors and still satisfy a given overall error for that class. For a given θ, the offer bounds that the σk's to be fixed can assume can be derived as follows.

Consider that $0 \le \tilde{Q} \le 1$ by definition. Therefore, $1 - \tilde{Q} \ge 0$. It is also always true that the quotient $Q/Q_k \ge 0$. Therefore the product

$$\frac{Q}{Q_K}\left(\frac{1-D-\tilde{Q}}{1-\tilde{Q}}\right)$$

in equation (A-47) can assume a nonnegative value if and only if $1 - D - \tilde{Q} \ge 0$. This implies that $1 - \tilde{Q} \ge D$, or, in expanded form

$$1-\tilde{Q} \ge \sum_{j=m+1}^{N}\left[\left(\frac{Q_j}{Q}\right)^2\left(\frac{\sigma_j}{\theta}\right)^2 - \frac{Q_j}{Q}\right] \qquad \text{(A-48)}$$

or,

$$1-\tilde{Q} \ge \sum_{j=m+1}^{N}\left(\frac{Q_j}{Q}\right)^2\left(\frac{\sigma_j}{\theta}\right)^2 - \sum_{j=m+1}^{N}\frac{Q_j}{Q} \qquad \text{(A-49)}$$

since $\tilde{Q} = \sum_{j=m+1}^{N} Q_j/Q$,

$$1 \geq \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^2 \tag{A-50}$$

and, in the limit:

$$1 = \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^2 \tag{A-51}$$

$$1 = \frac{1}{\theta^2} \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \sigma_j^2 \tag{A-52}$$

$$\theta^2 = \sum_{j=m+1}^{N} \left(Q_j/Q\right)^2 \sigma_j^2 \tag{A-53}$$

$$\theta = \sqrt{\sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \sigma_j^2} \tag{A-54}$$

is the lower bound on θ for all the σ_j, j = m + 1, ---, N which are known apriori.

alternatively, from (A-53):

$$\theta^2 = \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \sigma_j^2 \tag{A-54}$$

$$1 = \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^2 \tag{A-55}$$

note that

$$\sum_{K=1}^{m} \frac{Q_K}{Q} + \sum_{j=m+1}^{N} \frac{Q_j}{Q} = 1 \tag{A-56}$$

$$\sum_{j=m+1}^{N} \frac{Q_j}{Q} = 1 - \sum_{K=1}^{m} \frac{Q_K}{Q} \tag{A-57}$$

$$\sum_{j=m+1}^{N} \frac{Q_j}{Q} = \frac{Q - \sum_{k=1}^{m} Q_K}{Q} \tag{A-58}$$

hence

$$\left(\frac{Q}{Q - \sum_{k=1}^{m} Q_K}\right) \sum_{j=m+1}^{N} \frac{Q_j}{Q} = 1 \tag{A-59}$$

and therefore:

$$\left(\frac{Q}{Q - \sum_{K=1}^{m} Q_K}\right) \sum_{j=m+1}^{N} \frac{Q_j}{Q} = \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^2 \tag{A-60}$$

letting

$$Q' = \frac{Q}{Q - \sum_{K=1}^{m} Q_K} \tag{A-61}$$

and substituting (A-61) into (A-60):

$$\sum_{j=m+1}^{N} \left(\frac{Q'}{Q}\right) Q_j = \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^2 \tag{A-62}$$

or, assuming each term contributes to the total an amount proportional to Q_j/Q:

$$\frac{Q'}{Q} Q_j = \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^2, \quad j = m+1, \ldots, N \tag{A-63}$$

$$Q' = \frac{Q_j}{Q} \left(\frac{\sigma_j}{\theta}\right)^2 \tag{A-64}$$

$$\frac{Q'Q}{Q_j} \theta^2 = \sigma_j^2 \tag{A-65}$$

and,

$$\sigma_j = \theta \sqrt{\frac{Q'Q}{Q_j}}, \quad j = m+1, \ldots, N \tag{A-66}$$

are upper bounds on σ_j, $j = m + 1, \ldots, N$, which can be fixed and still satisfy if σ_j, $j = 1, \ldots, m$ are assumed to be zero. Equation (A-66) provides the analyst with valuable guidance in the apriori selection of values for one or more of the subclass errors in a source class.